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PROCEEDINGS OF THE SECOND INTERNATIONAL CONFERENCE ON BITUMINOUS COAL

NOVEMBER 19 to 24, 1928

VOLUME I

CARNEGIE INSTITUTE OF TECHNOLOGY

PITTSBURGH, PENNSYLVANIA

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FOREWORD

In presenting the Proceedings of the Second International Conference on Bituminous Coal I take occasion, on behalf of the Carnegie Institute of Technology, to thank all those who through their support and participation have made possible its success. I wish particularly to thank those individuals and companies whose financial assistance has aided in defraying the very considerable expenses of the meeting. We are again deeply indebted to the members of the Advisory Board for their advice and encouragement.

The great interest in the Conference was indicated by the registration amounting to about two thousand. There were delegates from twenty-two countries. It was found necessary to enlarge the program and to give more opportunity for discussion than was possible at the first international meeting in 1926. The Proceedings therefore are presented in two volumes. It will be noted that the discussions instead of following each paper are printed after each group of papers.

The success of the Carnegie Congresses and the developments in fuel technology which may be expected in the future encourage us to believe that another International Conference would be welcomed and would be of value. It is not, however, possible at this time to fix a date. I shall be glad to receive suggestions either as to the proper time for the next meeting or the subjects to be treated.

THOMAS S. BAKER,
President, Carnegie Institute of Technology.

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ADDRESS OF WELCOME

By Thomas S. Baker, Ph.D.

President, Carnegie Institute of Technology

I am deeply conscious of the great honor that is done the city of Pittsburgh by this assembly of distinguished scientists, engineers, and men of affairs. The officers of the Carnegie Institute of Technology are very happy in having been able to persuade men from all over the world to gather here to discuss questions of great moment to all sorts and conditions of men, from the householder to the most ambitious captain of industry, from the miner to the scientific recluse.

Pittsburgh and the Carnegie Institute of Technology, in recognizing the privilege of being the hosts of this Congress, perceive also a certain appropriateness that its meeting place should be in the city whose iron and steel would have been impossible had it not been first the City of Coal. The share of the institution founded by Andrew Carnegie in the enterprise is the result of the desire of its trustees and faculty to further the interests of the community where its founder worked and prospered and to carry forward the tradition of helpfulness to science and humanity which he established by his many philanthropies.

This is, first of all, a conference of scientists whose purpose is the advancement of science. It happens that the subject to be discussed, "*Coal*," is not only of the deepest theoretical significance but in our industrial age it is also the most useful of raw materials with which man has been endowed. We can think of no field of inquiry so full of interest whether we enter it from the point of view of the investigator, or from the standpoint of the practical man of affairs. Because coal can be studied from so many aspects, and because coal holds the attention of men of so many minds, a conference on its manifold uses cannot fail to be fruitful. The men of many minds will profit by exchanging their observations and their discoveries among themselves. The research worker will profit by learning the point of view of the practical man and the mine owner will profit by hearing what the chemist can accomplish—of the miracles which he can perform with the product of the mine.

The study of coal has as its object the unlocking of the riches that

lie hidden in this substance. Every step forward that is taken by the fuel technologist gives it an increased value. It may reveal a method of securing more work from a given unit. It may disclose a new and useful element which can be salvaged. It is a form of conservation of our natural resources which will benefit generations to come. We know that the modern and efficient methods of making power from coal are saving millions of tons of this commodity and are therefore extending the life of our deposits of fuel. We know that the introduction of the by-product coke oven has created a long series of industries which are producing every day a vast amount of wealth. And we may believe that we are just at the threshold of an era of new discoveries, some of which will be presented at this Congress, by which still more riches can be obtained.

We speak of conservation and we all recognize the propriety and wisdom of every effort that is made to prolong the life of our stock of raw material; but we perceive, too, that in spite of—in fact, because of—the advance in our knowledge of coal, the mining industry is in a languishing condition. This is no reason for disparaging or discouraging the investigations of the scientists. We could not, if we would, block the instinct to learn the secrets of nature. Nor can we limit the efforts to apply the discoveries of the laboratory to practical and useful ends. This Conference may reveal to the coal mine owner that his product may be used even more sparingly in the production of power; but it should do much more than this. It should have a positive value in that it should point out to him the necessity of forming a partnership with the skill and knowledge of the scientist, in order that he may find new uses for his commodity. It should show him that the same sort of ability that has narrowed his markets can discover the means of enlarging them.

The United States possesses one-half the known coal deposits of the world. This is one of the most potent reasons for the nation's industrial greatness; but its relative commercial importance to others will diminish unless we utilize our fuel resources as economically and intelligently as they; in other words if we, because of our opulence, fail to extract from the products of our mines their fullest value. Our national wealth can be increased in proportion to the scientific and technical skill that is employed in the utilization of our raw materials.

I refer to the great wealth of the United States not in a spirit of boastfulness or even self-complacency. It is to be hoped that we will employ our natural resources in such a way that they may be con-

served as long as possible and that they may form the basis of a happy civilization in which the comforts of life may be universal and in which there will be freedom from degrading labor and poverty. This can best be accomplished by learning from science all that she can teach us about employing wisely and thriftily our great national inheritance.

This Congress was organized in order that we might focus upon one of our greatest national assets all the scientific knowledge that can be obtained throughout the world. In this sense our Conference has a national meaning. It has also an international significance in that representatives of twenty countries have consented to share their knowledge with us. We are grateful for their generous minded interest in our problems. We welcome them most heartily. We hope that the hospitality that will be extended to them in the United States will show at least in a measure our appreciation of the sacrifices that they have made in undertaking the long journey to this city.

Coal has been spoken of as the mother of industry and ours is an industrial civilization. Therefore, as we study the source of industrial life, we study, in a sense, the basis of our culture. We know that the great industrial settlements will remain where power is cheap, but if we learn to distribute this cheap power over wide areas, we may find that the rural districts will be industrialized and the population of the cities de-centralized. The study, therefore, of the methods of producing energy and distributing it widely may result in changing the aspect of urban life. For where workers cannot receive remunerative wages the population decreases; and, as power is the source of industrial life, it is also the controlling factor in the earnings of workers. It is possible, therefore, that we may see a further extension of the tendency towards the de-centralization of population and the weakening of the urban centers. This prophecy would be justified if we considered only the question of the effects of the distribution of power over long distances.

But the new fuel technology may draw to the coal fields new industries which were not thought of a generation ago and thereby create a counter influence. More power may be generated at the mouth of the mine. The processing of coal will produce great quantities of gas, which formerly was wasted, but which in the future may be piped to distant cities, so that some day the gas that is burned in New York may come from the coke ovens of Pennsylvania. The processing of coal will also produce great quantities of tar which

will be distilled probably near the mines and the various stages of refining will ereate new enterprises out of what are now only laboratory experiments. Furthermore, the gases from the coke ovens will be treated in various ways to produee eommodities whieh can be used for fertilizing purposes. Chemical industries are likely to draw more and more elosely towards the coal fields. We can hardly coneeive of eonditions arising under whieh loealities where eoal is situated will not grow in importance. The newer chemistry will bring about new industrial developments, many of which will take place in the regions where the basie material is to be found. Whatever may happen to other parts of our country we ean prophesy with eomplete eonfidenee that those regions where soft coal is to be found will enjoy an ever inereasing aetivity and probably an expanding prosperity.

We who live in Pittsburgh, therefore, are eneouraged to hope for an even greater future than has been the past of our eommunity and largely beeause of the new seience of treating eoal. As the importance of our chief raw material is increased the importanee of our community will grow, as the value of eoal is enhanced the prosperity of our eity is extended. Its population must neeessarily expand beeause the day is at hand when we shall see many new industries, based upon eoal, developing in our midst.

The Pittsburgh eoal district will inerease in importanee as a souree of power because of the proximity of the rivers. The idea of a power plant at the mouth of the mine is at present impossible of realization unless there is at hand a large supply of water. This eondition we are able to meet beeause of our three great streams, so that more and more electrieity will be generated here to be used at distant points. To be sure, the exporting of eleetrieity over high tension lines will have the effeet of distributing manufaeturing over a larger area. On the other hand, it will give to our coal a greater value. It is a form of the working up of the raw material whieh is greatly to be desired, and it may be said in passing that the generation of electrieity may beeome only one of the produets of earbonization. The power house itself may be found surrounded by other plants that utilize the gas and tar which are secured in the proeessing of fuel. We ean easily think of the central station becoming the nueleus of a eonsiderable number of industrial enterprises. Only the coke will be employed under the boilers, so that while the eleetrieity from the great power house may push industries that depend upon eleetrieity

off into what are now regarded as rural districts, the working up of the by-products may create an opposite tendency.

For nearly a generation we have been hearing discussions of the possibilities of the power house at the mouth of the mine. Now the possibility of the gas plant in the coal field is being raised. There are objections. There will be the inertia that will retard a change from the present system of manufacturing gas near the city where it is to be consumed, but the experience of Germany in piping this commodity from the by-product coke ovens to distant points leads one to believe that sometime the same system may be adopted on a large scale in this country. For the present the abundance of natural gas will postpone the long distance piping of artificial gas; but the more coal that is treated the longer will our store of natural gas hold out.

Grave and complex economic questions arise in our minds when we think of putting into practice in our own district the new theories of coal treatment which will be presented at this Congress. First of all, where can a market be found for the new products? This can be answered only after a period of testing on a large scale, but at present much is being thrown away that has real value and assuredly the recovery and the marketing of this waste can in some way be made profitable not only to the public at large but to the capitalist. We hear the saying "the high cost of saving coal" but the fear implied in this expression will be valid only until we realize that waste in the long run is always an economic crime.

What has been said above implies that in the future less fuel will be transported in railway cars from the fields and more will be utilized at the place where it is mined. From our Pittsburgh district we shall send out electricity over high tension lines, our gas in pipe lines, and some day in the future possibly our liquefied coal in the same manner. The coal car will give way to the power line and the pipe line, and why not? since energy can be transported more cheaply in this manner.

A wide variety of chemical establishments will be located here because there will be at hand the tar of the by-product coke ovens and the low temperature retorts to be utilized. The district will be the center of various forms of the manufacturing of fertilizers. Not only shall we have more of the ammonium sulphate of the present by-product coke ovens to dispose of but the hydrogen or at least some of it gained in the coking of coal will be combined with atmospheric

nitrogen to produce other forms of fertilizer. When the time comes to supplement the nation's store of mineral petroleum, Pittsburgh will liquefy her coal to keep the Diesel engines and other internal combustion engines going. These are some of the industries which will be developed here directly as a result of our wealth of fuel. There are others which will be forced to the region where there are cheap power, cheap gas, cheap coke. If a satisfactory low temperature process for the treating of bituminous coal is established, we can think of Pittsburgh as supplying some of the needs of fuel for domestic purposes which are now met by anthracite.

We can imagine a better and happier economic and social situation for the people who live in the present mining fields when they find themselves in the midst of a group who gain their livelihood from a variety of enterprises. It is conceivable that some of the labor questions connected with the mining industry will be helped by a condition that offers the population an opportunity to change from one form of labor to another. This might be regarded as a sort of sociological by-product of the new methods of dealing with coal.

This may appear to be an optimistic description of our future. It assumes that the mining of soft coal, instead of being the sick member of the family of American industries, will enter upon a new and robust life. It also assumes that science will be encouraged liberally in the study of a raw material which contains so much potential wealth and that there will be capital at hand to utilize the discoveries which will be made in the research worker's laboratory. Two years ago at the opening of the First International Conference on Bituminous Coal, I said, "Farsighted men of affairs must perceive that something more than financial resources is necessary for commercial progress. Modern business demands two kinds of capital: money, and technical and scientific knowledge. A well organized and well directed staff of research men can achieve results in a business way which cannot be secured merely by great credits."

Pittsburgh has the capital in dollars. It has become strong in placing its money in infant industries that have grown to be giants. It has not the scientific capital which the business of the future will demand. It has not realized the immense dividends which will accrue from the investment of money in laboratories for the study of coal. The word research has today a more familiar sound in the ears of the man of affairs than was the case even a decade ago, but he has not been able to free himself entirely from the delusion that the man of science is unpractical.

Revolutionary and epoch-making discoveries have in their first stages but little that is of utilitarian importance. It is only later when the new scientific idea has become a commonplace that its value as a practical aid is perceived. The greatest contributions to human progress have come not from the men who have sought to find the solution of an every day problem but from the men who have sought to discover a fundamental law of nature. It is these workers who deserve most an opportunity to pursue their unworldly studies and in aiding such men the greatest material benefits will eventually be gained. And so here in Pittsburgh we should have a great research establishment for the study of coal—one which should employ not only the services of men who are striving to perfect the processes which have already been thought of, but also men who occupy themselves with the basic conceptions of physics and chemistry and who see in a lump of crude bituminous coal an opportunity of finding an answer to some of the enigmas of nature. It is my hope that as a result of this Congress, as a result of the wealth of scientific data which will be presented here, this generous minded community will perceive the opportunity, I may say the necessity, of creating a scientific establishment worthy of Pittsburgh and worthy of the industry which is the foundation of the city's greatness.

I have spoken of American hospitality and our indebtedness to the scientists from other lands who have made this conference possible. I bespeak for them not only a cordial and friendly reception as they visit our city, its industrial plants and those located in other parts of the country, but also I bespeak for them an attentive hearing. The papers which they will offer represent years of patient and thoughtful investigation. Some of those who will speak to you have reached a point in their studies where their ideas can be applied in a commereial sense. Our country is now looked upon as the world's banker and Americans have at all times been ready and eager to seize upon new conceptions which can be employed in business enterprises. A conference such as this performs a very useful purpose if it introduces scientists from other countries to American business men. It is a most happy form of barter when the capital of our country is exchanged for the scientific capital of other countries—when scientists from across the ocean leave with us their ideas and carry back with them the means of continuing and developing their investigations.

My brief address of welcome to the representatives from the many countries who are gathered here would not be complete without a

reference to our Conference as a contribution to a better understanding between nations. You gentlemen who come from across the oceans will gain a fuller appreciation of the American point of view and we of the United States will learn to value and, I am sure to admire, your efforts to advance knowledge and to promote good will. The scientist has a very special opportunity to create happy diplomatic relations. He is in his own person an ambassador of enlightenment and good understanding. Here in Pittsburgh you gentlemen, representatives of twenty nations, will meet on a common ground and will form in some cases enduring associations. There will also be established, I hope, as a result of this meeting, financial relationships between my country and others that are here represented. Thus while we discuss a subject that is possibly above all others materialistic, we shall be contributing in some measure at least to international concord.

Before I introduce the next speaker I have great pleasure in reading a message from Pittsburgh's most distinguished citizen who has been loaned temporarily, we hope—to Washington, the Honorable Andrew W. Mellon, Secretary of the Treasury.

THE SECRETARY OF THE TREASURY

WASHINGTON, D. C.

November 14, 1928.

My Dear Dr. Baker:

I regret that I cannot be present at the sessions of the International Conference on Bituminous Coal to be held in Pittsburgh on November 19th, and hope you will extend my cordial greetings to those present on this occasion and particularly to the delegates and speakers who have come from other countries.

I am deeply interested in the work in which the Conference is engaged. It is only by such interchange of ideas upon the part of scientific, professional and business men from all parts of the world that we can hope to solve the problems constantly arising in the development of the coal industry. In helping to increase the utilization of bituminous coal and its by-products, the members of the Conference are doing a work of great and lasting value and are thereby adding to the wealth and comfort of humanity.

Sincerely yours,
(signed) A. W. MELLON,
Secretary of the Treasury

DR. THOMAS S. BAKER, President,
Carnegie Institute of Technology,
Pittsburgh, Pennsylvania.

ADDRESS OF WELCOME

By T. P. Gaylord

President, Chamber of Commerce of Pittsburgh

It is indeed a pleasure and a privilege for me, on behalf of the Pittsburgh Chamber of Commerce, to extend to all members of this conference a most cordial welcome. Seldom are we honored with so distinguished a gathering of scientists as is represented by your conference. Many of you have come from faraway countries and your presence here is greatly appreciated. It seems most appropriate that here in the midst of the bituminous coal fields of Pennsylvania, in the heart of the greatest industrial center in the world, and within these halls of learning, you should meet for the purpose of devising ways of expanding the usefulness of this very important product, so abundantly supplied us by nature.

Gentlemen, you have much work to do, and it ill becomes me to consume much of your time, but may I very briefly bring to your attention one or two considerations relating to the subject of bituminous coal, regarding which we need your assistance.

Our coal industry during recent years has suffered a depression. Some of the underlying causes are not of your concern, but through the efforts and energies of just such men as you, who are here assembled, in this conference, the coal industry has suffered. You have made one pound of coal produce as much useful power as four to six pounds produced a few years ago. This is one of the important reasons why the growth and development of the coal industry has not been proportionate to the growth of industry in general. We have coal in abundance and we need to find new uses for it.

We have, coupled with this problem, another vitally important change taking place, affecting our economic structure. Through the continued advance made in the use of labor-saving devices, we find ourselves, notwithstanding the great increase in our manufactured product, with a surplus of labor. It is, therefore, highly important to our economic well-being that we develop new operations for those now left without profitable employment. Coal products seem to offer possibilities for such enterprises and it is to you gentlemen that we are looking for assistance.

The marked success of the first International Conference on

Bituminous Coal held here two years ago justifies the hope that even greater accomplishments will result from this second conference.

I want to take this occasion to express our appreciation to Dr. Baker for organizing and bringing together for a second time this very distinguished gathering of scientific men for a study of this important problem.

Gentlemen, the Pittsburgh Chamber of Commerce is at your service. If we can in any way add to the pleasure and comfort of your stay in our city, we hope you will feel free to call upon us.

LOW TEMPERATURE CARBONIZATION

The Work of the British Fuel Research Board During 1927–1928

By Dr. Cecil H. Lander

Director, Fuel Research Board, London

Read by Edgar C. Evans, Honorary Secretary, Institute of Fuel, London

At the First International Conference on Bituminous Coal held in Pittsburgh in 1926, the writer had the honor of describing the aims of the British Fuel Research Board and gave a short account of its program of work with the results achieved up to that time. On this occasion he proposes to amplify some of the information then given and generally to bring the account up to date. As it would be impossible in the limited time and space available to deal adequately with every branch of the work undertaken, a deliberate selection has been made of those items in the program which bear upon the subject of low temperature carbonization, since this subject is attracting a large amount of attention at the present time.

This question has always taken a prominent position in the work of the Board, especially as regards its national aspect. In Great Britain some forty millions of tons of coal are annually burnt in the raw state in the open domestic fire and, although the open grate has been shown by Dr. Margaret Fishenden to be more efficient than is generally assumed, it is quite definitely known that a large proportion of the smoke nuisance of Great Britain is due to this source. This method of heating is not unsuited to the climate of Great Britain, where long cold periods, such as are experienced during the winter in the United States and Canada, are unknown. The Englishman is accustomed to the open fire and likes it and whatever developments take place in the future in the direction of the greater use of gas and electricity the immediate problem of the elimination of domestic smoke can only be solved by the substitution for raw coal of some form of solid smokeless fuel which can be easily lighted and which will burn freely on the open fire. One form of such a fuel can be produced by subjecting raw coal of suitable quality to a preliminary distillation, using temperatures much below those associated with the present coal carbonizing industries. If a large proportion of the forty millions of tons of domestic coal could be subjected to such pretreatment the smoke nuisance would be largely overcome and at the same time there would be rendered

available a useful supply of low temperature or other tar from which motor spirit and oils of various grades and qualities could be obtained. This aspect of the matter often, however, grossly exaggerated by interested parties is not unimportant in a country which has to import the whole of its motor spirit and fuel and gas oils from overseas.

Various aspects of the problem of low temperature carbonization are being intensively investigated on the continents of Europe and America, but each country has its own conditions and its own special problems. For example, Germany has available large deposits of easily won and therefore cheap brown coal. The problem of converting these low grade and cheap fuels into higher grade fuels is a very different one from that of converting an already high priced good quality fuel into others which have but little higher commercial value. In the United States and in Canada the problem is not so much one of supplying a coke suitable for use in open domestic grates but rather for use in closed stoves, using soft bituminous coal as a raw material.

Low temperature carbonization processes may be divided into two distinct classes according to whether the tar can be regarded as the main product or as a by-product. It is obvious that unless the tar can command special prices on account of some valuable property it may possess, which is not possessed by natural oil, or unless the tar can be produced at a phenomenally cheap rate, undertakings which have to rely on this as their main product will always be subjected to such disabilities as have reacted from time to time in the shale oil industry which has always been at the mercy of waves of depression which coincide with waves of increased production and low prices in natural oil fields. If, on the other hand, one of the other products, coke or gas, can be worked as the main product so that the profits on these are sufficiently great to make the variation in the prices which can be obtained from the tars, such processes are in a much more favorable position from the point of view of their capacity of development to a point at which they, by their magnitude of operation, become a real material asset.

It has been claimed that by low temperature carbonization a low grade cheap coal can be treated so as to yield a higher grade and higher priced solid fuel, as well as valuable by-products, and in some cases there is undoubted truth in such claims. Commercial results of large scale working will, however, depend on the reasons for the present cheapness of the raw material. The position as it exists in America, Germany,

and other parts of the world has already been referred to. In these cases any fuel produced by carbonization would compete with higher grade and more expensive fuels, so that the price commanded by one ton of the product would be considerably greater than that commanded by the raw material. Also any increase in the demand for the product would not increase but might even decrease the cost of mining the low grade raw material.

In Great Britain the production of low grade slack coal is usually incidental to the production of more valuable sized varieties and the true mining costs are as great as those of the higher priced coals. The average selling price of the total product, slack and round coal must cover the average mining cost so that the loss on the lower grade slacks must be covered by the higher prices of the better grade product. If a process be developed for the manufacture from slack of a product which competes with high grade domestic coal, the demand for the latter will be reduced and the margin of profit on its sale would also be reduced. If the process be adopted on a national scale the profits on the high grade coal will no longer be sufficient to meet the losses on the low grade, the price of which will therefore rise. This will continue until a new economic balance is obtained and the general result will be a cheapening of the high grade fuel, but an increase in price of the low grade. The net result should be a gain both to the mining industry and the country generally, but the difference on price between the untreated low grade raw material and the higher grade fuel produced from it will be much less than in the case of the lignites or brown coals already mentioned. There would be a much less margin available for working expenses, and a carbonization process which might pay handsomely in one case might be quite hopeless in the other.

It is important to distinguish clearly between low quality and low grade. Brown coal, slack and fines of bituminous coals of small ash content are low grade but good quality, and would give a high grade coke if otherwise suitable. A slack of high ash content would be of low quality and would give a coke of reduced value. It is essential, if low temperature coke is to appeal to the domestic consumer, that it shall be of high quality and the ash content must be a minimum.

The above remarks are not intended to be in any way pessimistic but are merely introduced to sound a note of caution between the possibilities of certain processes, exceedingly valuable in themselves as affording an outlet on a comparatively limited scale, for low grade materials and their development by multiplication to such a scale that

they would be capable in Great Britain of appreciably affecting the smoke nuisance or of providing any considerable supply of oils and motor spirits from indigenous materials.

Summarizing, then, our major problem in Great Britain is to take a high priced raw material and convert it in enormous quantities into a smokeless fuel which ton for ton will not command a price much, if any, above that of the raw coal.

In the development of any commerical process of carbonization it is generally necessary that four distinct stages should be passed through:

(1) The suggested method must be investigated under laboratory conditions, where the varying factors involved can be subjected to close control, and where relatively high accuracy of measurement can be obtained.

(2) The process is carried a stage further by erecting an intermediate-scale unit, with a view to obtaining further designing data for a still larger unit. In this stage the plan will probably deal with several cwt. a day.

(3) Making use of the information yielded in stage 2, a full-scale unit must now be erected and tried out. The size of this unit would depend upon the type of plant, but might range between, say, 5 tons and 100 tons daily capacity. It is essential that this unit should be capable of multiplication to the full size of commercial unit without any alteration in scale.

(4) A commercial battery consisting of several units similar to those developed in stage 3 would be erected in some favorable locality, and the economic possibilities of the system examined in actual practice, and, if necessary, tested by actural commercial audit.

There are some sixteen plants in Great Britain of which units capable of dealing with about 10 tons a day are in existence, or in course of erection. Plants may be separated into two main groups:

(a) Those in which the solid product of carbonization is obtained in lump form sufficiently robust for transport and suitable for ordinary domestic grates.

(b) Those in which the solid residue is mainly small in size. It must be recognized, however, that a proportion may be obtained in lump form. The product will be utilized as pulverized fuel or converted into briquets. The tar yield in these systms is frequently greater than that associated with systems in which the production of a solid fuel in lump form is considered of primary importance.

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The processes may be again differentiated by the method of heating adopted, and this factor determines the type of gas produced. In systems in which the retorts are externally heated, the gas is small in volume and high in calorific value. In internally-heated systems, on the other hand, large volumes of low colorific value gas are usually obtained, except where steam is the heating medium.

The processes of low temperature carbonization typified in Great Britain embrace the stages of development from the laboratory scale to a fair sized commercial scale where the largest plant in the country, that of Low Temperature Carbonization, Ltd., at Barugh near Barnsley, is dealing with upwards of 200 tons of coal per day.

In 1924 the British Government Department of Scientific and Industrial Research which is executively responsible for the work of the Fuel Research Board was authorized to test at the request of the promoters any plant which claimed to have reached the stage where a full sized unit was available. The following processes have been tested and technical reports published:

The Coalite process, Low Temperature Carbonization Limited, Barnsley.

Midland Coal Products, Colwich, Nottingham.

Fusion Rotary Retort, Fusion Corporation Limited, Middlewich.

The Freeman Multiple Retort, British Oil and Fuel Corporation Limited, Willesden.

Crozier Process, Mineral Oils Extraction Limited, Wembley.

A test has also been published upon the Maclaurin plant at Glasgow. In this case those responsible for the development of the process have waited until they had reached the end of the stage of the complete commercial plant before asking for an official test to be carried out. This plant is designed for a throughput of about 100 tons, has been in operation since August, 1925, in the Dalmarnock Gasworks of the Glasgow Corporation, and since the coal stoppage has been steadily carbonizing from 50 to 70 tons of coal a day. A test is also being carried out at the present time on the plant working on the Mertz cycle at Newcastle and described by Mr. Sloan at the World Power Conference (1928).

Several other processes are also approaching the end of stage (4) where commercial units have been in operation for some time. These include the Illingworth process, a plant of 42 tons a day being in operation at Pontypridd; Midland Coal Products plant of 100 tons a day at Colwick, and the Fusion Corporation plant working on cannel at Welbeck. A

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TABLE I

YIELDS OF TYPICAL LOW TEMPERATURE CARBONIZATION PLANTS

	NAME OF RETORT											
	Parker Process*	Midland Coal Products*		Fusion Rotary*	Freeman Multiple*	Crozier Process*	Maelaurin Plant*	Leigh Smokeless Fuels, Ltd.	Illingworth Carbonization, Ltd.	Coal Extraction, Ltd.	Salermo Process	Fuel Research
	Name of coal											
	Dalton Main	Kirkby Top Hards	Briquets as Charged (from Washed Slack)	Welbeck Cannel	Kirkby Top Hards	Tullygarth	—	Caking Suitably Blended	Rough Slack Caking	—	Durham	Dalton Main
Moisture	2.4	9.6	14.5	1.8	9.4	11.4†	10.0	*Nil*	1.6	2.7	1.7	2.5
Volatile matter *less* moisture	35.8	32.5	33.3	46.6	32.1	34.0	33.7	33.0	33.0	14.5	32.9	32.6
Fixed carbon	57.2	52.6	47.1	36.8	51.6	44.2	50.7	62.5	54.0	78.3	60.4	58.5
Ash	4.6	5.3	5.1	14.8	6.9	10.4	5.6	4.5	11.4	4.5	5.0	6.4
Caking index	19					4	Up to 16	Caking blends	Caking coal		Caking	16
Ultimate analysis (dry coal):												
Ash	4.75	5.94	5.97	15.00	7.73	11.77						6.2
Carbon	80.05	77.72	77.36	70.20	75.03	71.40						80.1
Hydrogen	4.95	4.91	4.46	6.32	4.83	4.84						5.0
Sulphur	1.10	0.96	1.21	0.78	1.56	0.80						1.5
Nitrogen	1.60	1.94	1.47	1.50	1.36	1.58						0.9
Oxygen, etc.	7.40	8.53	9.53	6.20	9.49	9.61						6.3
Solid product:												
Cwt. per ton	13.9		7 5	11.7	13.3	15.4	9.9	14.0	15.2		15.2	15.1
Volatile matter, per cent	4.0		2.0	9.7	15.2	14.6	4 to 6	4.5	5 to 6		9.0	6.8
Breeze through ½-inch square mesh	4.6		15.0	99.6	59.3	17.4	About 16.0	*Nil*	5.3		64.8	17.2
Temperature of carbonization, °C.	550–850		Up to 1200	550	500	Up to 770–820			600		450	625

Tar:												
Yield of tar, gallons per ton	18.6		21.0	50.2	21.1	{16.4 / 2.4}	20.4 (wet)	20.0	17		20.3	17.3
Specific gravity	1.063		1.076		1.057	1.028	1.032	1 027	1.07	1.053	1.023	1.050
Spirit from gas, gallons per ton	1.78			3.7	0.85	0.80	typical tar		3.5			1.4
Water							1.70	1.5				
Up to 120°C							0.64					
Up to 170°C	4.7		1.1		6.9	4.1		9.5		6.1	7.0	3.4
120° to 230°C							5.47					
170° to 230°C	14.9		3.9		9.5	11.7		1.0		17.2	19.9	14.7
230° to 270°C	12.9		4.1		13.9	11.9	14.14	7.0		12.9	12.4	11.1
270° to 300°C												
270° to 310°C	18.1							13.0			11.2	
270° to 330°C						15.7						
270° to 345°C							26.04					23.4
270° to 360°C			26.9		29.8					23.0		
300° to 350°C								45.0				
Pitch	48.4		63.2		39.3	55.9	48.50	23.0		40.7	48.7	45.8
Loss	1.0		0.8		0.6	0.7	3.51				0.8	1.6
Tar acids	17.0		13.4		24.5	14.3				25.5		
Gas:												
Volume of gas, cubic foot per ton	5,620		58,300	2,740	1,720		33,849	10,000	6,200	3,505	3,920	5,188
Calorific value, B.t.u. per cubic foot	700		193	1,070	895		239.5	350	780	814	870	719
Therms	39.6		112.5	29.3	16.1		81.1	35	48.4	28.5	34.1	37.3
CO_2	4.0		1.6	6.5	10.2		7.0			4.5		4.0
C_nH_m	4.3			13.2	5.4		0.4			5.2		3.4
O_2	1.0		*Nil*	1.0	1.4		0.4			1.6		1 0
CO	6.1		28.1	6.4	6.7		12.2			5.9		6.6
H_2	37.2		16 6	17.1	9.1		20.2			15.0		31.3
C_nH_{2n+2}	39.6		4.4	49.5	50.4		12.9			53.0		42.6
N_2	7.8		49.3	6.3	16.8		46.9			14.8		10.6
"n"	1.23			1.59	1.4 (about)							1.27

*Plants tested by Fuel Research Board staff.

† As charged wet weather.

Note: 1 ton = English ton = 2240 pounds; 1 gallon = English gallon = volume of 10 pounds water.

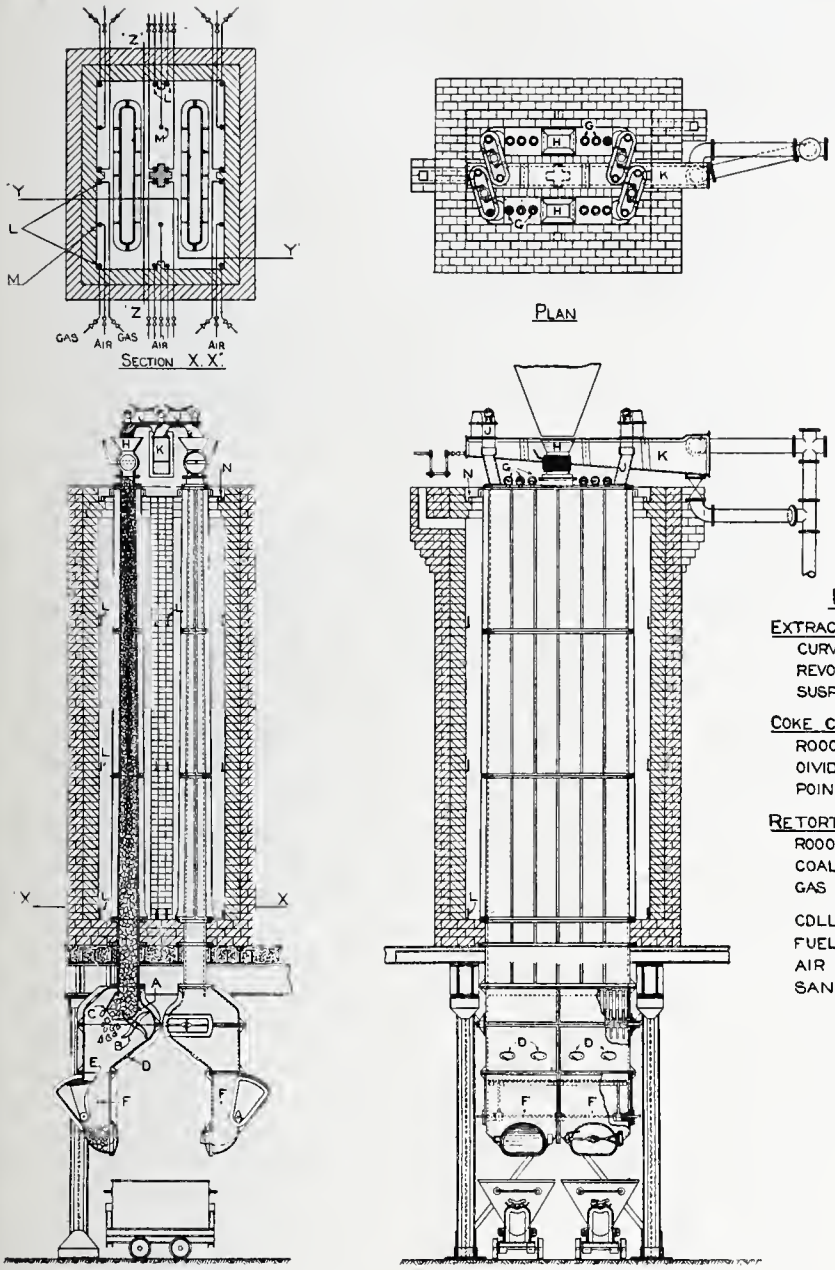
plant of the Leigh Smokeless Fuels, Ltd., designed for a throughput of 100 tons a day, is also available, but it is understood that this is not actually working at the present time, having been shut down for minor alterations.

The technical data quoted in Table I have been abstracted either from the official reports of the tests, where available, or were supplied by the firms themselves for the purposes of the Carbonization Conference held in February last at Birmingham, England.

The Fuel Research Station was erected and equipped with the definite object amongst others of being able to carry investigations of fuel treatment through all the preliminary steps to success in stage 3; their subsequent economic success or failure can only be decided in conjunction with industry. It is in essence a full sized works in which provision has been made for the adequate investigation of apparatus on a full size scale, in which it has generally been found convenient so to design plants that their throughput will be in the neighborhood of 10 tons a day. In order that work might proceed uninterruptedly and at the same time without undue haste, arrangements were made with the South Metropolitan Gas Company, who provided the site at a peppercorn rent, for the sale of such surplus products—tar, ammonia, gas and coke—as might be available. The Station has grown rapidly to meet the needs of dealing with the many specific problems which have been introduced both at home and from all over the British Empire, and it now contains full sized units of various types of retorts for high and low temperature carbonization, briquetting machinery, water-gas and waste heat recovery plants, steam boilers, gas producers, and gas and oil engines. A full scale washery comprising typical units and a Bergius plant capable of dealing with about 1 ton of coal a day, have recently been added to the equipment. Operations are conducted continuously, night and day, throughout the year. It has always been considered essential that the utmost accuracy commensurate with the scale of the work should be attained, and the staff now has no difficulty in obtaining weight balances within about 1 per cent.

The plant which has been developed at His Majesty's Fuel Research Station is shown in Figure 1, and the following is a brief description of the details of its construction and method of working of the particular design designated Type E.

Two retorts which were in use for 2 years are 21 feet high by 6 feet 6 inches by 7 inches, widening to 6 feet 10 inches by 11 inches. They are made of ordinary gray cast iron of good quality, and are divided into



SETTING OF CAST IRON RETORTS TYPE E
FOR
LOW TEMPERATURE CARBONISATION
H.M. FUEL RESEARCH STATION, GREENWICH

FIG. 1

three sections, which are cast in halves. The metal is 1 inch thick, and strengthening ribs project as far as the edge of the flanges along each side of the retort. The general construction is shown in the drawing.

The extractor gear consists of a curved grid or comb (*A*) which supports the charge at the base of the retort. This design was adopted after discussions with Messrs. Woodall, Duckham & Company; certain of its features are embodied in patent No. 251,043 of that firm. Behind this revolves a set of arms (*B*), which , passing between the teeth of the comb, push the coke off them. A rush of coke is prevented by weighted bars (*C*) suspended so as to rest against the ends of the teeth, as shown in the diagram. Arrangements are made to allow of rodding vertically up through the teeth of the extractor gear and also horizontally in a position above the teeth.

As originally designed, it was intended that the extractor gear should be worked continuously, and therefore the coke chamber below the extractor gear was divided by a door (*E*), the intention being that when the door was closed the coke below it should cool off for a period of say $1\frac{1}{2}$ hours, while the hot coke was collecting above the door. When the cooled coke had been discharged, the hot coke would be allowed to fall into the lower chamber to cool, and the upper door again be closed.

In actual practice it has been found more satisfactory to operate the extactor gear for a short time only at intervals of one, two or three hours according to the nature of the coal undergoing carbonization, consequently, the inner door of the coke chamber is not used. By this semi-intermittent method of working it has been found possible by adjusting the length of the quiescent periods to the properties of the coal, to work a large variety of coal from strongly coking coals to those possessing only feeble coking properties.

Steam can be admitted to the coke chamber (at *F*) immediately above the doors. With the use of steam so admitted there are indications of an increased yield of tar, but beyond sealing the retort from inrush of air the exact function of the steam is uncertain. This matter is under investigation at the present time.

Various systems for admitting coal to the retorts have been tried; for example, two feed valves feeding into the side of the upper casting, two feed valves on the top of chutes placed directly over the retort. The system at present in use is the most satisfactory so far—that is to say, one feed valve (*H*) in the center of the cover of the retort, the valve itself being as close as possible to the heated zone.

Two gas offtakes (*J*) are arranged one at each end of the major di-

ameter of the retort, and these discharge into the top of the collecting main (*K*) with as short a connection as possible. Arrangements are made for continuous circulation of liquor through the collecting main, which may be kept wet or dry as required.

It was considered at first that the most suitable coal for use in these retorts would be either a medium caking coal or a blend of caking and non-caking slacks. Experiments have been carried out on such blends, and the maximum throughput thus reached amounted to 3.0 tons per retort per day.

Non-caking nuts are the easiest to work, give the highest yield of tar, and the greatest throughput. Slightly caking nuts approach this very closely. Strongly caking nuts require no rodding and give a good throughput and a good yield of tar. With a mixture of lump coal and fines some rodding is necessary, and the rate of throughput and the yield of tar depends on the proportion of fines. With fine coal both the throughput and yield of tar are low, and rodding amounting to possibly eight minutes per two hours is necessary on each occasion of charging.

It was found that the fine coal (through a $\frac{3}{8}$-inch screen), which amounted to 50 to 60 per cent of the Durham coal used, could be dealt with by briquetting. Several tons of ovoid briquets were made with 4 to 6 per cent of pitch as binder, and it was found that these briquets, when mixed with the lump coal, could be carbonized at an increased throughput. When, however, the briquets were passed through the retorts by themselves, the coke formed was so hard and strong as to be difficult to extract. The small coal was therefore mixed with varyng percentages of breeze prior to briquetting. Of these mixtures 20 per cent low temperature coke breeze, 74 per cent coal, and 6 per cent pitch, was the most satisfactory. These briquets passed through the retort at a good throughput and formed excellent coke.

The coke from the fine Durham coal (strongly caking) was very strong, hard and compact, and arrangements have been made to test its suitability for foundry purposes. Table II shows the results of trials of several types of coal.

The heating of this experimental setting was arranged on a system which has been found particularly successful at the Research Station. The two retorts are surrounded by a brickwork setting rectangular in plan into which fuel gas is led by means of plain steel pipes (*L*) bent vertically upwards at the end into various corners built into the internal face of the setting. The chimney effect of the corner causes the flame to cling closely to the brickwork and not to wander, and so flame contact

TABLE II

Results of some typical trials of various coals in Fuel Research Station Retorts Type E

TEMPERATURE SETTING	COAL	DURATION OF TEST	THROUGHPUT PER RETORT PER DAY	GAS			TAR	COKE				REMARKS
				Cubic feet per ton	Calorific value (B t.u. per cubic foot)	Therms per ton		Hundredweights per ton	Breeze, per cent through ½-inch square mesh	Volatile matter less moisture: On ½ inch	Volatile matter less moisture: Through ½ inch	
°C		*hours*	*tons*				*gallons per ton*			*per cent*	*per cent*	
625	Durham (run of mine): through ½-inch, 40 to 60 per cent	120	2.69	5,420	710	38.48	11.1	15.04	18.8	6.9	8.3	Charging at 2-hour intervals; difficulty encountered with No. 2 retort only; rodding at the bottom of No. 2 retort necessary for discharge of coke
610	Durham (run of mine): through ½-inch, 52 per cent	97	2.74	5,750	660	37.95	11.2	14.12	10.6	6.7	8.6	Retorts charged at 3-hour intervals; slight rodding at the tops and bottoms of retorts necessary
625	Crushed: 48 Butterley, 52 Wearmouth	92	3.03	6,840	547	37.41	11.9	14.59	20.8	7.8	10.2	Retorts charged at 1-hour intervals; trouble was experienced only for a short period on the third day in retort No. 2, when the coke was inclined to hang

620	Nut coal, Mitchell Main (cold)	96	3.52	4,860	729	35.45	13.1	15.30	11.9	8.4	12.3	Retorts charged at 2-hour intervals; easy working; no trouble
605	Screened on $\frac{3}{8}$-inch round mesh, Durham: through $\frac{1}{2}$-inch, 27 per cent	120	3.31	5,890	681	40.11	14.1	15.53	13 0	7.2	9.2	Retorts charged at 2-hour intervals; No. 2 retort gave trouble on second and fourth days of test, but no trouble experienced with No. 1
625	Nut coal, Mitchell Main (preheated)	96	4.05	4,460	752	33.54	14.31	15.88	11.5	7.3	11.4	Retorts charged at 2-hour intervals; very easy working; no rodding required
625	Dalton Main Nuts: through $\frac{1}{2}$-inch, 35 to 43 per cent	74	3.66	5,190	719	37.3	17.3	15.14	17.2	6.6	8.2	Retorts charged at 1-hour intervals; very easy working; no rodding required
625	Garforth Nuts: through $\frac{1}{2}$-inch, 18 per cent	72	3.38	6,150	577	35.5	18.4	12.89	19.5	7.7	10.1	Retorts charged at 1-hour intervals; very easy working; no rodding required
610	Briquets: 74 per cent Durham coal; 20 per cent low temperature coke breeze; 6 per cent pitch	72	3.03	5,160	557	38.54 (On dry coal and pitch)	13.8	15.51	12.0	6.9	8.0	Retorts charged at 2-hour intervals; no serious difficulties in working; No. 1 retort gave a little trouble during last day of test

Note: 1 ton = English ton = 2240 pounds; 1 gallon = English gallon = volume of 10 pounds water.

with the cast iron retort walls is avoided. The heat from the flame is conducted along the brickwork so that the retorts are heated very largely by radiation from the brickwork. There are three sets of burners dividing the vertical height of the retorts into three portions.

The air supply is furnished through ports in intermediate positions (*M*) between the burners at each level in order to retard the combustion of the gas and lengthen the flame. In the top set of burners however, the air supply is led close to the burner so as to shorten the flame.

Sixteen burners and six air ports are situated at each level as shown in Figure 1. Half way along each side of the setting a 4½-inch vertical projection of brickwork is built. One gas burner is placed in each corner of the setting and one in each corner made by the projecting brickwork. In the center of the setting a brickwork pillar making a cross in plan is built from the floor upwards in order to give four more corners into which burners may be placed and thus insure symmetrical heating. The inside of the setting is perfectly plain from top to bottom so that there is no obstruction to the upward travel of the burning gases. When working smoothly, the retorts are charged alternately, and it was found that there was no necessity to alter the heating gas supply in any way. If, however, trouble is experienced with the coal in the retorts, then it is very convenient to be able to reduce the gas supply to the top section of the retort; that to the lower parts of the retort has to be altered very rarely.

These retorts having developed defects due to the distortion of the metal were finally shut down in February, 1928, after two years of satisfactory working. The setting has now been replaced by two further retorts of a slightly modified design adopted on the advice of the British Cast Iron Research Association who have also furnished specifications for metals which should withstand more satisfactorily the temperatures used, viz., 625°C. Experiments in the new retorts are now proceeding actively, the results obtained to date being satisfactory. These results appear to show that after further experience in working it will be possible to increase materially the throughputs above those given in Table II.

During 1926 the British Department of Mines and the Department of Scientific and Industrial Research gave a great deal of consideration to the best method of carrying any suitable process to the final stage of its development, namely a trial under strictly commercial conditions, and on a commercial rate, extending over several years. In view of the importance of the decision arrived at, the following extract is quoted from the 1926 report of the Fuel Research Board.

Those processes of low temperature carbonization "which produce the largest proportion of lump coke suitable for domestic use also produce considerable quantities of rich gas which form a valuable portion of the products of carbonization. If such a process were to be adopted throughout the country very large quantities of gas would be produced, the full value of which could only be realized with the coöperation of the gas undertakings. It was accordingly decided by the government, with the concurrence of the Fuel Research Board, that Mr. (now Sir David) Milne Watson, the Governor of the Gas Light and Coke Company and the president of the National Gas Council, should be asked for his assistance in this matter. Questions of commercial development are somewhat outside the scope of the Department of Scientific and Industrial Research, and it was accordingly decided that the matter should be handled by the Mines Department, with the Department of Scientific and Industrial Research as technical advisers. Mr. Milne Watson was seen by representatives of the two departments and asked whether he was prepared to consider all existing processes in detail and would advise the government:

"(a) Whether, in his opinion, any of these processes had reached such a point of development that it was worth while for his company to continue the experimental development on a large scale

(b) If so, whether he considered the selected process or processes sufficiently promising to justify his company in taking the entire risk of this development;

(c) If not, whether he would submit a scheme after discussion whereby the government would be asked to bear a part of the risk involved."

"Mr. Milne Watson agreed to go into the matter, and after he had received reports from his staff after examination of all the processes being developed both in this country (Great Britain) and on the Continent, he reported that he considered the one developed at the Fuel Research Station was the most promising for development in conjunction with a gas works. He did not consider that any process was so far proved as to justify his company in taking the whole risk of its development, but he was so far impressed with the desirability of coöperating with the government by putting the matter to a practical test as to offer a site for a 100-ton a day plant, and to undertake to erect the plant and run it as continuously as is reasonably practicable for a period of three years, and to carry out experiments and researches

in connection with the carbonization of coal, provided that the government would pay the original cost of providing and erecting the new plant necessary on the selected site, which already had many of the requisite conveniences.

"It was finally arranged that a subsidiary company should be formed termed the 'Fuel Production Company, Ltd.,' the capital of which has been guaranteed under the Trades Facilities Act. The gas company will act as managers for the fuel company and will bear all running and management costs. At the end of 1930 the gas company have an option to purchase the plant, or if they do not wish to do this they will clear the site and dispose of the plant, etc., on behalf of the fuel company. Details of the plant are now being worked out, and it is hoped that it will be at work during next winter.

"It has been agreed that the company shall keep full records of experiments and all statistics necessary to demonstrate the results obtained, and to keep proper accounts in connection with the business of the fuel company. The Mines Department have the right to inspect the accounts, and the Research Department has the right to inspect the plant, its working, and all technical records. Steps have been taken to safeguard the public interest in any patents that may be taken out as the result of working the plant, and full details of the plant and the results obtained will eventually be published and be freely at the disposal of any company desirous of working the process. Thus it will be seen that The Gas Light and Coke Company are in effect carrying out the work for the benefit of the whole industry.

"This arrangement should provide definite information as to the commercial possibilities of the process.

"It should, perhaps, be emphasized here that the Fuel Research Station retort was considered the most suitable type for trial in conjunction with a London gas works, and it does not follow that there are not other types, some of which, while possibly unsuited for gas works, may be equally or better suited for use under other conditions, e.g., for erection at power stations, or at the collieries for the treatment of special types of coal.

"While we welcome the action taken to test the Research Station plant on a commercial scale, we realize that similar trials of other plants and in other circumstances are required in addition, and we welcome the efforts being made in this direction elsewhere."

The plant now in course of erection under this scheme by the

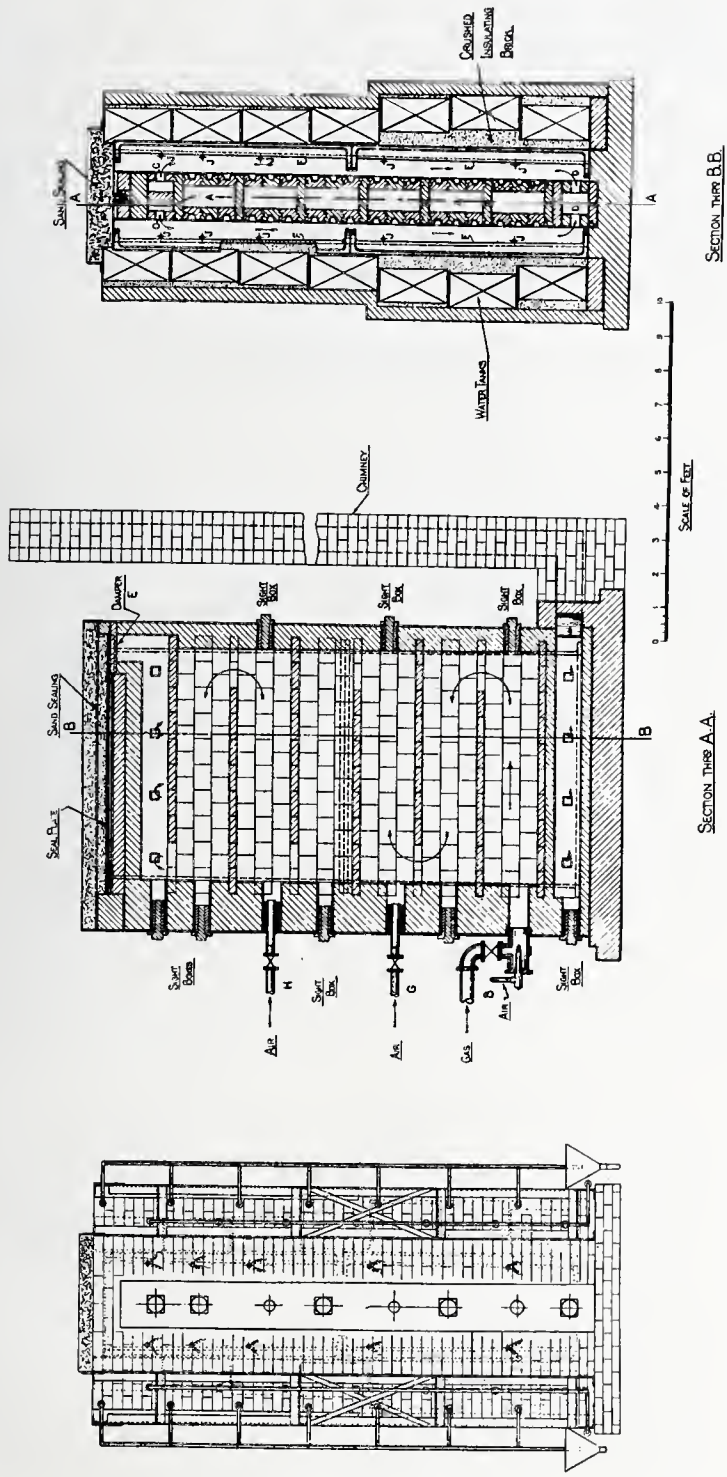


FIG. 2. APPARATUS FOR INVESTIGATING THE HOT WALL METHOD OF HEATING LOW TEMPERATURE RETORTS

Fuel Production Company that is situated in the Richmond Gasworks of The Gas Light and Coke Company and is expected to be operating before Christmas. Certain minor alterations in the design of the retorts themselves have been introduced as the result of further experience obtained with Retorts E and also the new setting already referred to. The method of heating Retort E already described, whilst giving excellent control and uniform heating, would be somewhat complicated in a large commercial battery of retorts, as there are 24 separate burners per retort. It was accordingly decided to try whether a hollow wall containing sizsag flues, such as is sometimes used for heating coke ovens, could be adapted to give uniform and easily controlled heating of low temperature retorts where it is important that the temperature should be as nearly as possible constant and uniform, but should not exceed, say, 625°C.

A model setting two-thirds full size, was therefore erected for trial purposes, details of which are given in Figure 2. It consists essentially of a hollow wall *A*, with the flues so arranged that the gases, entering at the bottom through the burner at *B*, pass backwards and forwards as indicated by the arrows until they reach the top. From here they either pass out through the holes *C* and down the outside of the wall, then through the holes *D* and up the chimney to atmosphere, or they may be by-passed straight to atmosphere through the top of the setting by means of damper *E*.

In order to approximate closely to the conditions of heat transfer obtained in carbonizing, two half sections (*F* in figure) of one of the old "*D*" retorts were erected on either side of the hollow wall, representing a section of retort 14 feet 0 inches high. Water tanks were placed behind these retort sections, separated from the retort sections by suitable lagging, and the whole surrounded by an outer wall.

The heating gas is supplied only through burner *B*. Air is supplied at *B* and may also be supplied at levels *G* and *H*.

The temperature of the retorts is measured by means of the thermocouples *J* supported on the face of the retort sections, and in close contact with them.

While it is desired to keep the whole surface of the retort at a temperature as near as possible to 625°C., the rate of heat transfer through the retort wall is not, in practice, uniform at different levels. A temperature exploration was made of the retorts when actually carbonizing, which gave the temperature gradient through

the retort walls at different levels. A thermal balance gave the total heat transfer into the retort. From this data was calculated the lagging required between the retort sections and the water tanks at the different levels of the experimental setting so as to reproduce the working conditions of the retorts. Measurements of the water flowing through each tank, and its rise in temperature, gave directly the amount of heat passing through the retort wall. It was found that the distribution of heat flow was attained, but that

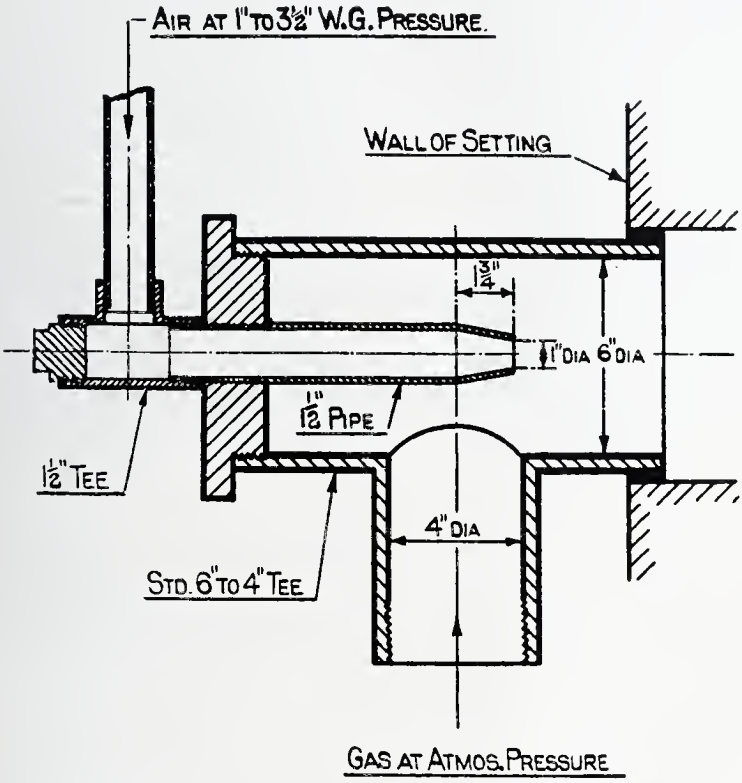


FIG. 3. BURNER FOR COAL GAS, PRODUCER GAS, AND WATER GAS

the actual heat flow was considerably greater than in the retorts when carbonizing.

A number of experiments has been carried out using coal gas, water gas, cold producer gas and hot producer gas, with the flue gases either passing down the retort face and up the chimney, or by-passed through the top of the setting.

It was found that more even heating was obtained when the flue gases passed between the hot wall and the retort, and with all types

of gas used it was found possible to get very even heating of the retorts when all the gas and a portion of the air was supplied at the bottom at *B*, and the remainder of the air at one higher point, namely, at *H*.

With this arrangement there was no difficulty in obtaining complete combustion when the setting was once heated up, but when starting from cold it was necessary to add the secondary air at *G* until the proper temperature had been obtained in the flue.

This type of setting has been adopted for the new retorts at the Fuel Research Station, and for those at the Richmond Gas Works.

The advantages over the old method are that there is only one burner per retort, and at the most five air inlets, and that the temperature of the retort is not so liable to sudden changes should anything occur to interfere with the normal passage of material through the retort.

Several special burners have been designed and tested in this setting with a view to producing one which will burn any gas, from rich coal gas to producer gas, without deposition of carbon. Figure 3 shows the type finally evolved. This burner after being tried out in this setting has been adopted for heating the new retorts at the Fuel Research Station, and at the Richmond Gas Works. It can be used with coal gas, water gas or producer gas without any alterations whatever.

When burning coal gas, the important point is the amount which the air pipe projects beyond the intersection point of the pipe centerlines. Having found this dimension, perfect smokeless combustion can be obtained with any proportions of gas and air at the burner, and with variations of pressure between wide limits.

Although similar methods of heating have been used in high temperature practice the application of hot wall heating to temperatures of about 600°C. introduced new and difficult problems. The data obtained and the final successful application of this method have proved exceedingly useful to industrialists who, while not interested in the subject of low temperature carbonization, were concerned with similar problems in other processes. The experimental work was closely followed by certain large firms who sent members of their technical staff to the Fuel Research Station to follow its working and to obtain first-hand experience of its operation.

From the foregoing it will be gathered that considerable progress has been made both at the Fuel Research Station and by industry

in the solution of the low temperature carbonization problem as it affects Great Britain; since the writer spoke before the Bituminous Coal Conference in Pittsburgh in 1926, and in conclusion the words of the Committee of the Privy Council for Scientific and Industrial Research may be quoted:

"Many exaggerated claims have been made on behalf of low temperature carbonization; and the natural result of unfulfilled prophesies is that in many quarters undue pessimism prevails. We consider that neither extreme optimism or pessimism is justified, since we have yet to learn the facts on which a sound judgment of the commercial success on a large scale of any low temperature carbonization process can be based."

Information is rapidly becoming available both from the work of the Fuel Research Station and that of the many firms and individuals engaged on the problem and it may now be said with confidence that there exist special local conditions in various parts of the world under which one or other of the plants developed by the sounder firms can be expected to be commercially profitable. To what degree the process may develop to the scale of becoming a really large industry and a real factor in the world's fuel economy in the widest sense only time can tell.

CATALYSIS

Applied to the Conversion of Hydrocarbons

By Dr. Carl Krauch

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The laws of chemical equilibria and thermodynamics enable us to predict whether a reaction is possible or not. For instance, proceeding from a simple hydrocarbon such as methane, a large variety of other hydrocarbons may be obtained such as gasoline, petroleum, unsaturated hydrocarbons, and, by oxidation, alcohols, aldehydes, ketones, acids, and so on.

If what has thus been predicted had to be put into practice, difficulties would soon be found to arise from the fact that thermodynamics is not concerned with the velocity of chemical change, which implies that nothing is said about the conditions necessary for control of the direction and extent of reaction.

The industrial chemist is therefore obliged to concern himself not only with thermodynamical calculations but also with the considerations of how to control the velocity of reactions, and with their interpretation.

Why do molecules not get into the equilibrium predicted by thermodynamics in spite of the vast number of molecular collisions which condition the reactions? The reason is that nature has enclosed the reactivity inherent in the molecules like a nut in a shell; to set this reactivity free, we have to crack the shell and to crack it, of course, in the easiest possible way. In other words, the falling of free energy characteristic of all chemical change does not occur spontaneously but must be induced; in every process the reacting molecules have to be fed with energy to overcome the impediments resisting the course of chemical change.

Now, it has been found that the simplest representatives of hydrocarbons, such as methane, are especially hard nuts to crack; the energy of activation necessary to get them in the state of reactivity is very considerable. This implies that chemical changes of hydrocarbons proceeding in stages are extremely slow; practically they do not occur at all unless special means are applied. To show that this holds good in the view of kinetics would here lead too far.

The means by which to overcome the impediments referred to are, above all, the catalysts. In certain cases the introduction of electrical or radiating energy into the reaction system comes in question; namely in cases requiring an especially high introduction of energy, the thermic equilibrium of which is, accordingly, very unfavorable. Where catalysts offer little or no advantage, nothing remains to be done but to bring the molecules into the necessary high states of activation by the introduction of foreign free energy, that is, through impacts of electric particles as they occur in silent discharges, or through absorption of radiating energy—photochemically. Nature shows us these photochemical processes in a grandiose way in the assimilation of carbonic acid brought about by sunlight, the process upon the products of which we all live.

However, in the case of all such changes that can be carried through purely thermally at temperatures and pressures available for us—here belong most reactions of the hydrocarbons—the catalysts are of inestimable value in order to start reactions, to control them, and to obviate secondary and subsequent reactions that are possible but not desirable.

Before going more closely into the matter, I should like to say a few words about the notion we have formed of the peculiar effect of catalysts. If a gas-reaction is to take place without catalysts, the activating energy necessary to overcome the molecular impediments can be imparted to the molecules only through the mutual collisions due to thermal motion, the effect of which is not specific. For the purpose of controlled reaction, which is what is generally aimed at, only certain bonds of the reacting molecules have to be loosened. If the energy is imparted by collisions, all degrees of freedom of the molecules—their translatory, rotatory and oscillatory motions—unavoidably take up energy, thereby loosening bonds not intended to enter into reaction. Consequently, unnecessary consumption of energy takes place. To give an instance, in the mutual collisions of methane molecules in the gas-room, thermal energy is consumed to bring about velocities in the direction of the three dimensions of space, rotations around the three axes of the tetrahedral molecule, and vibrations of the H-atoms within the molecule, executed against the C-atoms as well as against each other. According to the stability of the molecules, these degrees of freedom of the rotatory and the vibratory energy become capable of taking up energy only above certain temperatures. Thus, in this mechanism of unspecific intro-

duction of energy the molecules become activated in quite a variety of points whereas for a specific reaction generally one certain bond only need be loosened. These difficulties can be obviated since through the attachment of the molecules to the catalysts or, in terms of physics, through the oriented adsorption to which they are subject under the influence of the atomic fields of the catalysts, complexes are formed in which the controlled loosening of certain bonds is started. Only slight amounts of energy, varying according to the reaction in question, are then required to bring about a complete loosening of those bonds, a combination of the fragments, an insertion of other molecules, and so on. In terms of reaction kinetics, catalysts act in such a way that, together with the reacting molecules, they form attachment complexes which require slight activating energy. These attachment complexes in their turn can, with but slight activating energy, be converted into the desired reaction products.

For the sake of completeness, it may be mentioned that the effect of the catalysts in conversion of hydrocarbons consists not only in increasing the reactivity of the hydrocarbon molecules; they are also of importance in hydrogenation and dehydrogenation, oxidation and dehydration, in consequence of the peculiar activating effect of the contact substances on hydrogen, oxygen, water, and so on.

I now come to such cases of catalytic conversions of hydrocarbons as have been elaborated in the last few years in the I.G.; cases which seem to be of interest scientifically or technically. I shall chiefly speak about conversions in which hydrocarbons are converted into other hydrocarbons. In these cases, the hydrocarbons are subjected to the action of catalysts either alone or in the presence of other participants in the reaction—oxygen, or compounds giving off oxygen or hydrogen.

It is characteristic of the previously mentioned controlling action of the catalysts that such catalytic reactions are very sensitive to changes in exterior conditions. In general, the process takes the desired course within only a slight interval of temperature, pressure, and time of contact of the reacting substances with the catalyst.

The changes which hydrocarbons under the action of contact substances can undergo by themselves consist either in splitting up or in polymerization. Besides these changes, others have become known in which only the structure of a molecule has been changed, but not its composition, for instance, displacements of twofold or threefold link-

age, and formation as well as splitting up of cyclic compounds. The catalytic splitting up of hydrocarbons—I count here also the separation of hydrogen, dehydrogenation—seldom occurs without subsequent reactions, as the molecular fragments have a tendency to combine to larger stable complexes according to the conditions of the experiments. That is to say, the splitting-up is followed by polymerizations or condensations.

A case of pure catalytic splitting up studied by us, is the dehydrogenation of ethane to ethylene: $C_2H_6 = C_2H_4 + H_2$. By means of a suitable catalyst it is possible to stop the splitting at the ethylene stage; that is to say, to prevent subsequent polymerization. The reaction has a rather pronounced optimum as regards temperature and the time of contact of the gases with the contact substance.

The splitting-up of the methane, first member of the paraffin hydrocarbons, into its elements has been carried out technically for the production of carbon black; it may also serve for the production of hydrogen. By means of catalysts, the rather high splitting temperature may be lowered.

The incomplete splitting-up of methane is explicable only by the subsequent polymerization of the resulting radicals. This reaction has often been investigated because of the fact that the catalytic conversion of methane into ethylene, acetylene, benzene, and so on, is of great technical interest. Methane is largely convertible into acetylene, ethylene, and other hydrocarbons if conducted over heated metals such as platinum, certain metalloids, oxides, salts, and ceramic materials, provided that the proper conditions of streaming and cooling have been maintained; however, the requisite temperature is rather high, and it is also difficult to avoid the depositing of carbon upon the catalyst.

The splitting-up of methane into acetylene and hydrogen is one of the previously mentioned cases in which the application of catalysts offers no advantage. On the contrary, the presence of catalysts or of solid substances in general, especially the walls of the reaction vessels, can act unfavorably by urging the reaction in the undesired direction of the formation of carbon and hydrogen. This phenomenon is probably most closely connected with the influence to which the methane molecule is subjected while being adsorbed on solid surfaces. A computation according to Nernst's heat theorem, shows that the equilibria between methane and acetylene,

$$2\ CH_4 = C_2H_2 + 3H_2 - 92\ \text{cal}$$

under atmospheric pressure, at various temperatures, are as follows:

	per cent
At 800°	3.2
At 1000°	20
At 1200°	62

On the other hand, the equilibrium between methane and its elements: $CH_4 \rightleftharpoons C + 2H_2$ is markedly shifted to the side of complete decomposition at a temperature as low as 900°. Accordingly, when heating methane to the temperature required for the formation of actylene, it is important, in order to avoid decomposition of the gas into its elements, to pass through the critical temperature—which is below 1000° – as quickly as possible and to eliminate as far as possible the presence of heated walls. These conditions are excellently fulfilled if methane is heated in the electric arc. A further improvement of the working-process is obtained by adding hydrogen to the methane, as, according to the laws of thermodynamics, the formation of soot is thereby retarded. The electric arcs used up to the present in chemistry—for instance, the mechanically moved arc of Pauling, the magnetically moved arc of Birkeland-Eyde, and the stationary arc of Schönherr—cannot be used as they are for the splitting-up of methane, on account of the peculiar electric behavior of hydrocarbons. If, for example, we take Schönherr's oven, in the air combustion process it is possible to obtain arcs 8 to 10 meters long, whereas in the decomposition of methane, if the same amount of electric energy is employed, arcs only 60 to 80 cm. long can be obtained and these only by special means. Schönherr's arc oven, as adapted by us, produces almost complete conversion of methane into acetylene, provided that pure methane is used, diluted by a 1 to $1\frac{1}{2}$ fold volume of hydrogen, and passed repeatedly through the arc; moreover, a high-grade hydrogen is obtained. The use of electric energy for this chemical process is very economical. One kilowatt hour yields 85 to 90 liters of acetylene, which means that the efficiency of the electric energy is 35 to 40 per cent. In the cases of the generally known air combustion processes the efficiency is only 2 to 3 per cent. Similarly it is possible to work up other hydrocarbons, such as tar oils, and petrol products to acetylene.

I should like to say a few words about the polymerization of the lower members of the olefine and acetylene series. In the case of the higher hydrocarbons the conditions are so complicated that the split-

ting-up and the polymerization are hardly distinguishable. The polymerization of acetylene investigated by Berthelot and R. Meyer without catalysts and by Zelinsky with active coal, leads, as is known, to a tar about half of which consists of benzene. We have investigated a fairly large number of substances with reference to their polymerizing action upon acetylene, and ascertained that their efficiency as catalysts rests upon the fact that they favor the formation of a special form of deposition coal, which, in its turn, influences the condensation process catalytically. Comparing the appearance of the catalysts experimented with we found that on all substances of good catalytic activity graphitic carbon of a metallic lustre was deposited, whereas the substances, on contact with which none or but slight amounts of condensation products were formed, had been covered by dull soot.

The contact substances formed by passing over acetylene are also well suited for the polymerization of ethylene, propylene, isobutylene and other unsaturated hydrocarbons. The formation of the active deposition coal from these gases themselves is also possible; however, a very careful treatment, taking a long time, is required.

From the conversions which take place when simple hydrocarbons are heated in the presence of catalysts, I now pass to conversions of higher hydrocarbons. As already remarked, these reactions, in most cases are of a very complicated nature, consisting of various single processes that take place side by side or immediately following one another, such as splitting-up, polymerization and isomerization. The problem is made more difficult by the fact that in the case of the higher hydrocarbons, whose catalytic conversion is of a special practical interest, the raw materials are usually very complicated mixtures which are either difficult to separate, or inseparable by our present methods; and, moreover, they vary in composition according to their sources.

Anhydrous aluminum chloride has a special significance as a catalyst in the cracking process. It was used for the first time by Friedel and Craft in 1877 for the splitting-up of hydrocarbons, and later, applied to mineral oils by G. W. Gray and McAffee. It brings about a far-reaching conversion of the large hydrocarbon molecules, forming low boiling products which, unlike the products obtained with nearly all other catalysts, consist only of saturated hydrocarbons. The aluminium chloride can be formed advantageously from aluminium and dry hydrogen chloride in the oil to be split-up. In this

connection it has been found that by previous treatment of the aluminium with certain solutions of metallic salts it is possible so to activate it that the yield of gasoline increases considerably. The fact that when working with activated aluminium the cracking temperature may be as low as from 100 to 180° is worth mentioning.

Another peculiar class of catalysts is composed of certain complex compounds discovered by Meerwein. These are combinations of organic acids with the so-called Ansolvo acids, i.e., metallic salts such as zinc haloids, or inorganic neutral molecules of various kinds. The Ansolvo acids have the property of combining with the anions of the organic acids to form complex anions whereby the dissociation equilibrium is displaced in favor of hydrogen ions, and the result is a strengthening of the organic acids. According to Meerwein, surprising catalytic effects can be obtained with such compounds. Among them we found very good splitting-up catalysts for hydrocarbons. For instance, with complexes such as:

Antimony pentachloride	+ naphtoic acid
Sodium chloride	+ formic acid
Alumininum chloride	+ phthalic acid

we obtain from high boiling oil products and tars a good yield of gasoline which is a gasoline distinguished by a high percentage of aromatic and olefine hydrocarbons and a strikingly low percentage of naphtenes. Here, too, the strong polar nature of the catalysts leads us to presume that the catalytic process takes its course via an electrostatic orientation of the hydrocarbon molecules. In spite of the complicated, frequently changing and in general, not accurately known composition of oil products and tars, it has become possible by means of catalysis to control their conversions. However perfect the cracking processes of today may be without the conscious use of catalysts, it must be admitted that catalysts are undoubtedly a very valuable aid in increasing the yield of certain desirable products and in restricting the formation of undesired products.

Besides the splitting of hydrocarbons of high molecular weight under the influence of catalysts, we have studied their synthesis from hydrocarbons of low molecular weight. Of special practical interest for us in Germany is the manufacture of lubricating oil. We are not, as you fortunately are, in the position of being able to separate lubricating oils of the most diverse kinds in more than sufficient quantities directly from crude oil. Can inferences be drawn from

the properties of hydrocarbons that are good lubricants as to the constitution of their molecules? Evidently such molecules must have the property of ranging themselves in films easily sliding against each other and of forming an adsorption layer on the surface of the bearing metal in which the molecules take a definite orientation. For the constitution of molecules that fulfil these conditions it may be presumed that rules, similar to those given by Langmuir and Harkins in their investigations respecting molecular films on the surfaces of liquids, hold good.

Anhydrous aluminium chloride has proved an excellent catalyst in the manufacture of lubricating oil, its polymerizing effect preponderating over its splitting-up effect under suitable conditions, and especially at low temperatures. If, according to Allenet's process, aluminium chloride is suspended in an indifferent solvent, for instance, petroleum-ether, and gaseous olefines are introduced, they are polymerized to lubricant hydrocarbons of high molecular weight. We have introduced olefines in middle oils containing aluminium chloride. We found that not only do polymerization processes take place, but also condensations between the middle oil hydrocarbons and the olefines introduced. It is also possible that the two processes overlap. The end-result is that out of the thinly liquid middle oil highly viscous lubricating oils are obtained which, in their essential properties, are practically the same as the natural oil. Another catalyst well suited for the manufacture of lubricating oils is the borofluoride, as found by Fritz Hofmann.

Before I leave the sphere of catalytic conversion of hydrocarbons without foreign reaction participants, and turn to oxidation and hydrogenation, I should like to speak about an investigation carried out in our works which, though not lying in the catalytic but in the photochemical domain, seems to me of importance here, as it offers information respecting the stability of the bonds between the individual atoms in the hydrocarbons. We wanted to investigate the splitting-up processes which take place at the impact of particles rich in energy upon gaseous hydrocarbon molecules. It is to be assumed that these processes are similar to the changes, inaccessible to immediate observation, which the molecules undergo in the field of force of the catalytic surface. We did not avail ourselves here of the method of electron impacts, as, under certain circumstances, the charge of the electrons might influence the splitting-up process; moreover, the investigation of the fragments is made difficult in conse-

quence of the fact that the gas or the vapor to be bombarded with electrons must be highly diluted. Nor did we use silent discharges, for the processes here are so complicated that it is scarcely possible to identify individual processes and to interpret them. The method developed by us in 1924 in connection with the research of your countryman, R. W. Wood, and the German physicists, J. Frank and G. Cario, on the so-called resonance radiation, proved to be satisfactory.

The phenomenon of resonance radiation consists in this, that the atoms of a metallic vapor, say mercury vapor, when raised to the so-called excited states, i.e., states rich in energy, by irradiation with light of a definite wave length begin to radiate in the absence of foreign gases. The presence of foreign gases prevents this resonance radiation of metallic vapors, the excited metal atoms losing their energy upon colliding with the molecules of the foreign gas, the latter becoming chemically changed. Thus Frank and Cario could prove that, in hydrogen at very low pressure (some hundredth millimeter mercury), such excited Hg-atoms produce H-atoms. In our research laboratory at Oppau, it was ascertained that such chemical changes take place even at atmospheric or higher pressures. It was further ascertained that the primarily formed atoms or radicals with other additional gases yield most diverse conversions which are often difficult to bring about in other ways. This application of the optically sensitized light-reaction makes it possible to obtain many kinds of products from simple gases. Experiments with pentane showed that the splitting-up of the molecules of this hydrocarbon takes place in two directions. On the one hand, H-atoms are separated from the molecules, on the other hand C—C linkages are disrupted. The resulting radicals combine to form hydrocarbons with fairly long chains, among which hexane, nonane and decane could be identified. This method was developed by us and, later on, independently in your country by H. S. Taylor, A. L. Marshall, and others, in whose hands it led to interesting results. In this method the energy of each colliding particle is accurately known from spectroscopic measurements—for Hg-atoms it amounts to 113 cal. per mol.; it affords conclusions concerning the stability of the molecular linkages and elucidates the primary processes in catalytic conversions. In the case of pentane both C=C and C=H linkages are disrupted by activated Hg-atoms and the result is in conformity with the value for the previously mentioned splitting-up energy of these linkages in aliphatic hydrocarbons, as calculated by means of Fajans' cycles.

Among the catalytic conversions of hydrocarbons in the presence of oxygen and steam, the conversion of methane is again of special interest, since large quantities are obtainable in coke furnace gas as well as in natural gas. Its suitability for the production of hydrogen makes it one of the most important basic materials of the chemical industry in this age of the synthesis of ammonia and the hydrogenation of crude oil and coal.

Apart from direct splitting-up of methane into its elements, hydrogen is obtainable from methane through oxidation with oxygen or with steam:

(1) $$CH_4 + \tfrac{1}{2}O_2 = CO + 2H_2 \quad + 7 \text{ Cal.}$$
(2) $$CH_4 + H_2O = CO + 3H_2 \quad - 51 \text{ Cal.}$$

Through oxidation with steam it is possible to obtain from one volume CH_4, 3 volumes H_2 and, if the resulting CO is converted with steam to CO_2 and H_2, 4 volumes of H_2 can be gained; that is, twice as much as by direct splitting-up. The heat required for the reaction is, however, considerably greater, while the temperature of the reaction is not considerably lower than in the case of the direct splitting. We succeeded in finding catalysts which enabled us to carry out the reaction at relatively low temperatures. We have worked this process both in the discontinuous mode, in which the reaction vessel was heated periodically and the mixture of methane and steam passed through it, and in the continuous mode, heating the vessel from the outside.

In the case of oxidation with oxygen or air it is possible to get from one volume CH_4, 2 volumes H_2 or, after conversion of CO with steam, 3 volumes H_2. Technically, this reaction is easier to carry through than the other two mentioned, because it has a positive heat of reaction. Also here, the use of catalysts lowers the reaction temperature.

The various processes for the production of hydrogen from methane may with advantage be combined; for instance, methane may be converted partly with oxygen and partly with steam, thus covering the energy requirements of the steam reaction by the surplus of heat of the oxygen-reaction and making it possible to work continuously.

The thermic splitting of methane may be so controlled by special precautionary measures that no complete decomposition into the elements occurs, but that acetylene results as a conversion product of a primarily formed radical. Similarly acetylene may be obtained as a product of the partial combustion of methane with oxygen.

As regards the technical realization of the oxidation of methane to oxygenic derivatives, especially to methanol and formaldehyde, as described in numerous patents, hardly anything has so far become known. Ethylene can be oxidized to formaldehyde more easily than methane. By taking, contrary to the methods hitherto preferred, undiluted ethylene and employing catalysts—those containing phosphoric acid and boric acid proved to be the best—we succeeded in obtaining yields of formaldehyde amounting to 70 to 90 per cent of the value theoretically possible, the ethylene being passed over the contact substance only once. This progress provided the basis of a technical process which, however, we abstained from employing for the reason that about the same time we had achieved the methanol synthesis from CO and H_2 that promised to supply a cheaper basic material for the manufacture of formaldehyde in the traditional way.

The oxidation of medium and higher hydrocarbons of the paraffin series has found increasing interest in the last few years. Especially in this country, as publications show, much work has been done in connection with the oxidation of gasoline and other crude oil fractions with air or oxygen, mostly under the application of catalysts. We ourselves directed attention chiefly to the oxidation of the paraffins that we have available in the by-product tars obtained in the process of low temperature distillation, or gasification, of our Middle-German lignite and also the tar which becomes available in the hydrogenation of lignite, in quantities varying with the methods of working. As the paraffin market is relatively small, it was imperative to find new outlets for the quantities obtained in our Leuna-Works. We have accordingly endeavored to carry on its oxidation to fatty acids required in the soap industry, of which acids considerable quantities have to be imported at the present time.

The problem of manufacturing fatty acids for the purpose alluded to was not easy to solve. We again have before us a basic material which varies greatly and the composition of which is not accurately known. In the treatment of the heated paraffin with air it is not sufficient to attain a definite degree of oxidation within a short time. Fatty acids suitable for clear soaps can be obtained from the oxidation product only when the reaction is controlled. It must be borne in mind that the slight difference in the prices of paraffin and fatty acids makes it impossible to use complicated and expensive methods of working up the oxidation product.

Our experiments were at first concerned with the question of the

velocity of oxidation with air which, according to the available literature, was said to be very slight. Taking care to bring about a very intimate contact between air and paraffin by transforming the paraffin into a foam, and applying certain catalysts, we succeeded in reducing the time of oxidation from several days to a few hours, and in lowering the reaction temperature considerably. By these means, the formation of undesired products is restricted, and the yield of fatty acids increased. A small part of the paraffin together with easily volatile oxidation products—chiefly products with less than 10 C-atoms—pass together into the receiver, and can again be used for oxidation. The main product remaining behind in the oxidation vessel consists of fatty acids, wax alcohols, and unchanged paraffin, in quantities varying according to the conditions of oxidation. The paraffin and alcohols from the main product return likewise to oxidation. Besides normal acids, the fatty acids may contain oxy-acids. We have found various ways of refining the fatty acids to such a degree that, in the judgment of soap experts, they stand comparison with good fatty acids derived from natural fats.

Concerning the mechanism of oxidation of paraffin, our notion is as follows: The oxygen seems to attack the hydrocarbon molecules not at the ends, but about the middle of the carbon chains, forming large fragments. In favor of this view it may be said that the acids in question contain about half the number of carbon atoms of the hydrocarbons from which we start; further, that only very small quantities of carbonic acid and oxidation products of the lower members of the paraffin series, are formed; possibly also the considerable formation of esters of the fatty acids with wax alcohols of approximately the like number of carbon atoms.

With the fats obtained from the refined fatty acids and synthetic glycerine, we have carried on experiments on animals which proved successful.

Passing on to the catalytic hydrogenation of hydrocarbons, I should like to confine myself to the field at present in the focus of public interest, namely, the hydrogenation of coal, and its distillation products.

The hydrogenation of coal is, strictly speaking, an overlapping of cracking or coking, and hydrogenating processes. The point is, that at the moment of splitting-up the hydrocarbons, hydrogen is attached to the primary fragments so as to form compounds of lower molecular weight enriched in hydrogen, and the formation

of coke is avoided. For this purpose, hydrogen is applied under high pressure, and care is taken to regulate the temperature accurately in the reaction vessel. In this way the drawbacks of the usual cracking or low temperature distillation processes are eliminated, though not completely. These draw-backs are the considerable formation of methane, which means that gasification goes too far; and the formation of heavy oils and coke, which means that dissociation goes too far.

Heretofore, in the case of a certain basic material, the variability of kind and quantity of desired products such as gasoline, kerosene, gas-oil, lubricating-oil, and heating-oil, was very small. Moreover, it was practically impossible to remove completely the oxygen and the sulphur contained in the basic materials and to avoid especially the formation of phenols which are not desirable.

I will now show you how the position has changed in the course of time. At first, the application of catalysts seemed hopeless because contact substances then known were destroyed by poisons such as sulphur and oxygen contained in the basic materials oil, coal and tar. The harmful influence of contact poisons is characterized by the fact that they preferably occupy just those parts of the catalyst surface that are chemically the most vital, the "active spots," and that they thus eliminate their effects upon the reacting molecules. However, the experiences gathered by us in the last thirty years in the field of catalysis and its technical application led us to try the hydrogenation of coal with catalysts. The problem of the prevention of the poisoning of the contact substances through oxygenic and sulphuric compounds had occupied us a good deal in the catalytic production of ammonia. In the course of our occupation with the hydrogenation of *carbon monoxide* and *carbon dioxide* we found a new class of catalysts that proved suitable for the purpose of hydrogenation; these catalysts, consisting chiefly of oxides difficult to reduce, were, unlike those known up to that time, but little susceptible to sulphur and other contact poisons. This new class of catalysts offered, moreover, a typical example of the control of reactions as mentioned before. According to the catalysts applied and the conditions of reaction chosen, we were able to obtain from carbon monoxide or carbonic acid and hydrogen either methanol exclusively, or, together with its higher homologues in varying quantities, chiefly propyl, isobutyl, hexyl and heptyl alcohols, aldehydes and ketones or hydrocarbons.

With such knowledge, we attacked the problem of the hydrogenation of coal and its products. In the first experiments we found catalysts by means of which tar could be converted into a water-clear liquid,—gasoline—, only 10 per cent of the carbon content being lost in the form of gaseous products. These catalysts proved to be immune to the contact poisons of the tar, especially oxygenic and sulphuric compounds. After this success the same principles were applied to the pressure-hydrogenation of crude oil and coal and we managed to produce, without difficulty, the most diverse marketable products, such as gasoline, kerosene, gas-oil, lubricating oils, and so on, in quantities varying according to the catalysts employed. We are thus enabled to adapt the hydrogenation process to the fluctuations of the market.

Another important advance that could be made through the application of catalysts is the improvement of the quality of the products obtained. The phenols that resulted formerly from the oxygenic compounds of hard coal and lignite have disappeared. Oxygen is removed as water, or as carbon dioxide, and only hydrocarbons are formed. Likewise, the sulphur contained in coal and lignite is volatilized in the form of hydrogen sulphide. A sulphur content of, say, 5 parts by weight, as related to 100 parts by weight of carbon in lignite has fallen to 0.1 per cent and under, in the gasoline produced from it.

Another case showing the importance of catalysts in this field is the suppression of knocking in gas engines by the use of iron pentacarbonyl, lead tetraethyl etc., which appears to be a case of negative catalysts.

The excessive velocity of the reaction, namely the explosion-like combustion of the fuel, being reduced to the desired measure by such additions. The investigations of J. A. Christiansen, H. S. Taylor, Pease, and Baeckstroem, on the effect of inhibitors in thermic and photochemical oxidation processes, lead to the supposition that the effect of negative catalysts rests, in the cases of strong exothermic reactions, upon the circumstance that they break off the reaction chains formed; in other words, they intercept the activation energy passed on from one reacting molecule to the next; their suitability for this purpose is explained by their generally very complicated molecular structure and, consequently, high capacity to take up energy in the form of vibration energy. In these cases, the mechanism of negative catalysis is not exactly the contrary to the mechanism of positive catalysis before mentioned. It is possible

that in some cases the mechanism works in just the opposite manner, namely, when a negative catalyst forms an attachment-complex with a reacting molecule in which a linkage of the molecule is not loosened but stabilized. Thus considered, the controlling action of a contact substance may be explained by saying that the catalyst is capable of loosening some linkages of a molecule and stabilizing others.

For an explanation of the action of those catalysts found by us suitable for hydrogenation, the important fact seems to be that they are in nearly all cases metallic compounds occuring in various stages of valency, easily convertible one into another. I should like to bring to mind the notion that the electrostatic deformation of the hydrocarbon molecules that occurs in the catalytic conversion seems to be favored specially by attachment to metals in which there is an easy exchangeability of the outer electrons, in other words, a tendency to change the stages of valency. Indeed, contact substances that had been working for some time contained the metal in various stages of valency. A valuable aid for such investigations is the x-ray method of examination of solids.

In adapting our laboratory experiments to large-scale production we had to struggle with some difficult problems in spite of our vast experience in working with gases under high pressures, such as are involved in the ammonia and methanol manufacture. Thus we found that iron, in certain forms, had to be avoided in the hot parts of the apparatus, as it favored the formation of methane. In addition to the attack of hydrogen upon the hot pressure-bearing walls, as observed in the ammonia and methanol syntheses, we encountered corrosions through H_2S, water vapor, and CO_2, formed from the sulphuric and oxygenic compounds of coal or crude oil. To find out the most suitable material for every part of the apparatus was not easy. We placed new problems before the steel and metal industries.

Coal may be hydrogenated in the form of powder distributed in hydrogen or suspended in a suitable high boiling oil. The high boiling oil resulting in the first stage must be separated from the ash contained in the coal and from the coal particles not liquified. To carry through this separation in a technically satisfactory way was one of the most difficult tasks of the whole process. In our large-scale plant at Leuna we use the lignite from our Middle-German pits, the low distillation tar produced by ourselves from such lignite. At Ludwigshafen-Oppau we have been experimenting with other lignites as well as hard coal from various parts of the world. These experiments were intended to show the suitability of all such prod-

ucts for the manufacture of gasoline, which, for the time being, is our chief product. The difficulties we had to cope with after starting the first big oven at Leuna in April 1927 were extraordinary. However, in comparative experiments carried out in several big ovens working simultaneously, we recognized their causes and, in a relatively short time, succeeded in removing them. At present we have reached at Leuna an annual production of 70,000 tons of gasoline, of which 40,000 tons are obtained from coal. At the end of next year, we hope to be able to raise the production to 250,000 tons. The gasoline produced by us has found a ready market for the reason that in all essential properties it equals a good gasoline obtained from crude oil in the ordinary way.

The close resemblance that synthetic gasoline and other products obtained in the hydrogenation of coal, bear to their natural counterparts suggests that the origin of crude oil may be explained in this way. Peat and coal layers, after getting into greater depths, combine with hydrogen under pressure, thereby being partially converted in liquid hydrocarbons. The presence of hydrogen in the interior of the earth is deduced, as I may remind you, from the fact that both rocks and volcanic gases contain it. Apart from the generally accepted views of its formation, its origin might be attributable also to the action of water vapors at high temperature upon coal. We have ascertained that the products from various coals hydrogenated are optically active. Their activity rises, like that of crude oils, with their viscosity, that is to say, with their boiling limits; it is of the same orientation and order of magnitude.

I have shown you that catalysis, to which the chemical industry owes a number of new processes of outstanding significance, such as the sulphuric acid contact process after Knietsch and the ammonia synthesis after Haber-Bosch, begins to be successful also in the domain of the conversion of hydrocarbons, a domain of paramount importance for your country. The difficulties that barred its application in this field—the diversity of the basic materials and the large number of reaction possibilities, and the frequent presence of contact poisons, were successfully overcome by scientific research and a perfected technic. It must be our aim also in future to make new scientific knowledge the helpmate of technics, and to verify the scientific theories by means of technical achievement. The endeavours made in recent years, especially by American research workers, in the field of catalysis afford the best prediction that further technical developments in the conversion of hydrocarbons will soon follow.

CONTRIBUTIONS TO KNOWLEDGE OF THE TRANSFORMATION OF CELLULOSE AND LIGNIN INTO COAL

By Dr. Friedrich Bergius

Heidelberg, Germany

At the first coal conference I had the pleasure of reporting to you about the chemical and technical labors which have become the basis for the liquefaction of coal through the effects upon coal of hydrogen under high pressure.

Then I pointed out that the reaction for the liquefying of coal was found as a result of painstaking and purely scientific investigation of the transformation of cellulose into coal by a method which was developed in my former laboratory from 1910 to 1913. We established then that this reaction produces gaseous, liquid and solid substances, whose actual contents could be ascertained with some exactness, whenever the detrimental effect of the great heat generated therewith was eliminated by proper means. The most important result was that the reaction, consisting principally of the evolution of carbonic acid and water from the cellulose, under a temperature approximating 340°C. after eighteen hours produces a final state, characterized by the fact that the carbon content of the carbonic substance cannot be increased by continuation of the reaction. The coal thus obtained we called "End Coal," a product which is found to contain about 84 per cent carbon and 5 per cent hydrogen, when calculated from its ash-free and water-free substances. Experiments at lower temperatures revealed that this reaction showed the customary coefficient of reaction in chemical processes, i.e., the time required for attaining the same final result is doubled when the temperature is reduced by ten degrees.

Furthermore it was ascertained that the quantities of carbonic acid and water resulting from the reaction, stand in simple stoichometric proportion to one another and to the cellulose used. I have pointed out repeatedly that my studies of this reaction at that time led me to the postulation of a hypothesis of the constitution of coal. This hypothesis was the basis for successful experiments with the hydrogenation of coal, so that these purely theoretical investigations had the practical result of our liquefaction of coal.

Our scientific studies of the formation of coal, which gave promise of a clarifying investigation of the constitution of coal, had to remain in abeyance for several years, because our experiments with the liquefaction of coal proved too absorbing. But since the liquefaction of coal has led to positive technical results and since the "I. G. Farbenindustrie" has been fathering these labors, some of my collaborators, two years ago, resumed our former experiments with the transformation of plant substances into coal with a view, if possible, toward further clarifying the chemical nature of coal in course of time.

Today I should like to report to you concerning a part of these labors, which were undertaken by Dr. Karl Schoenemann during the last year. His task was to study the formation of coal from cellulose and lignin in proper apparatus with larger quantities and to ascertain the quantities of products formed by reaction as exactly as possible. Of course this was only possible when much larger quantities of raw materials were treated than in the former experiments, in which only from 100 to 200 grams of cellulose were brought to react. In such small quantities the possibilities of error are too great to recover in their entirety the products of reaction. It was necessary to deal with much larger quantities for each experiment, the result of which was to be precisely ascertained if detailed knowledge was to be had concerning the identity of "End Coal" with natural coal. In previous experiments, to be sure, the known reactions of coal could be positively effected with artificially produced "End Coal," but these familiar reactions could scarcely be taken as sufficient proof. Greater accuracy in this identification could be expected from a study of artificially produced "End Coal" by our method of hydrogenating under pressure, which has been well perfected during the last few years. If it can be shown that the hydrogenated product of artificial coal coincides with that of natural coal, it may be taken as proof that the artificially produced coal is nearly identical with natural coal, so that we may draw deductions from what has been ascertained concerning the composition of artificial coal, referring it back to natural coal.

In some measure we have now succeeded in bringing such proof of identity between the two coals. The main result of the labors, concerning which I can now report, is a quite exact statement regarding the quantitative result of the experimental production of coal in larger quantities.

In principle the method was the same which was employed years ago. A certain quantity of the material to be turned into coal is heated up to 340°C. for 24 hours in a pressure-resisting vessel together with water, which absorbs the heat of reaction and prevents local overheating. The products thus gained are assembled, measured and investigated with as much accuracy as possible. The method pursued appears simple, but the pursuit of the experiments, of which each demands months of attention, if the result is to be trustworthy, is exceedingly laborious.

In the experiments on cellulose we worked with 5 kgm. of initial material. For them apparatus was required which would resist a pressure of 200 atmospheres and which had a capacity from 50 to 60

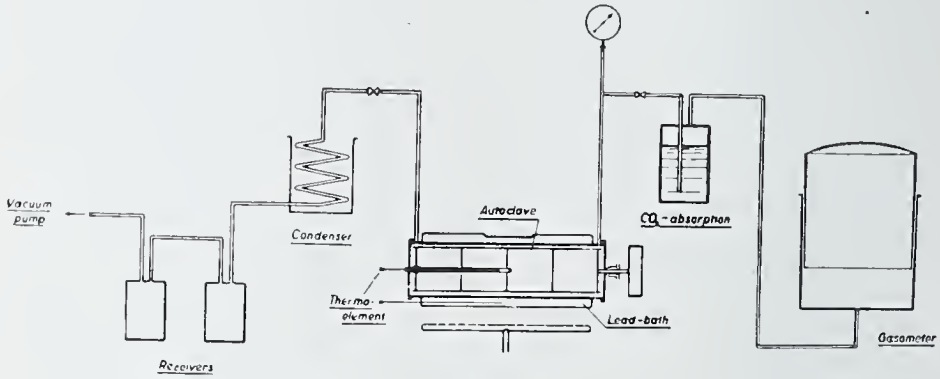

FIG. 1. DIAGRAM ILLUSTRATING CARBONIZING APPARATUS

liters. Of course the apparatus must be completely tight if an exact result from the experiment is to be attained.

Figure 1 explains the apparatus used. Into the reaction-vessel a carefully weighed quantity of cellulose is inserted with about 25 liters of water. A mixer is stirred in the contents to assure contact of the cellulose with the water. The vessel, which stands in a bath of molten lead for better distribution of temperature, is heated up to 340 degrees. Of course, maintenance of this temperature and proper measuring is of the greatest importance. After the process is finished, the gas, that has been formed and is partly dissolved in the liquid, is allowed to escape; the carbonic acid is absorbed; and the small amount of other formed gases is retained in a gasometer. Thereupon the entire liquid is distilled off and wholly condensed. The apparatus

must be very carefully handled and kept under observation to avoid losses of substance. The solid substance that remains in the reaction-vessel must be carefully removed from the vessel, after which its quantity is ascertained.

Our apparatus was such that it enabled us to conform precisely to the experimental requirements and to gather quantitatively all the reaction products. Notwithstanding the complicated nature of the details, the experiments could still be repeated with satisfyingly exact results.

Table 1 shows the quantitative recovery of the products of reaction.

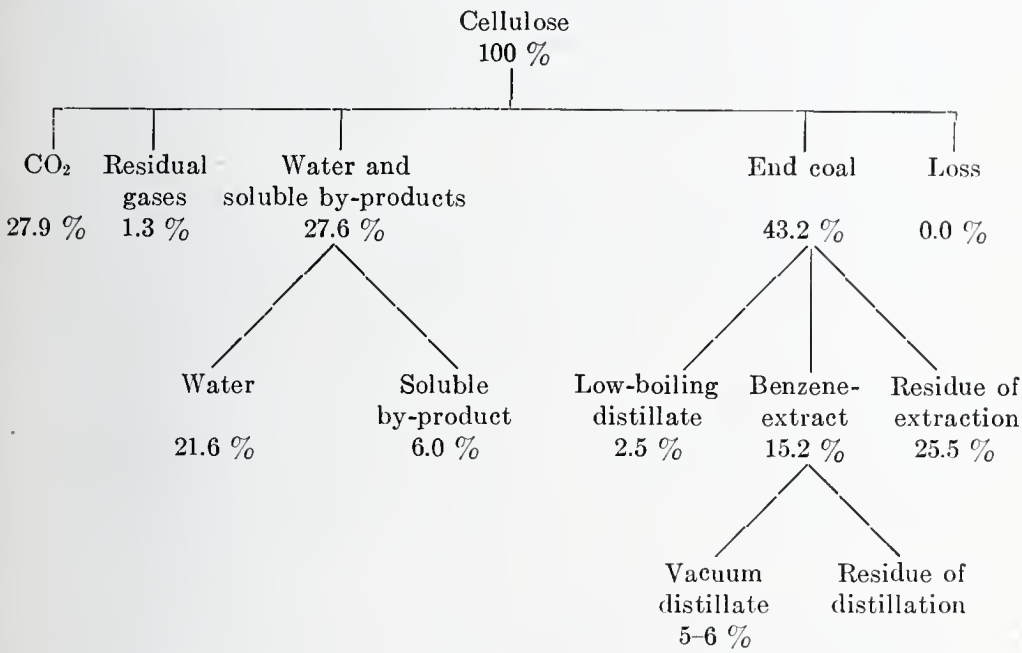

FIG. 2.

The ciphers with plus and minus marks in the table show the liabilities of error in our methods of experimentation. The table shows with extraordinary precision that all of the cellulose that was introduced into the vessel was regained in form of its reaction-product. The actual loss is between zero and 0.5 per cent.

The results of our investigation of the products are shown in Figure 2.

Besides 27.9 per cent of carbonic acid there are evolved 1.3 per cent remaining gases, which consist mainly of methan, hydrogen and carbonic oxide. In the 21.6 per cent water are 6 per cent soluble product, largely acetic acid. Altogether from 2.5 to 3.4 per cent of

acetic acid, calculated on the cellulose, are found in the products. From the "End Coal," with reference to cellulose, 2.5 per cent of low boiling products can be distilled, consisting in small part of carbonic acid and its homologous equivalents, but in the main part of oils containing oxygen, in which aliphatic and aromatic ketons are discernible.

The "End Coal" after liberation from its low boiling component parts was extracted by means of benzol. About one-third of the "End Coal" is soluble in benzol and of this extract from 5 to 6 per cent can be separated by vacuum distillation. Two-thirds of the "End Coal" consists of insoluble extraction residues.

In order to get a better insight into the "End Coal," which is affected to a relatively small degree by usual methods of separation, we submitted the "End Coal" to Berginization, i.e., liquefacation

TABLE I

CARBONIZATION OF CELLULOSE (CARRIED OUT WITH 5000 GRAMS CELLULOSE)

PRODUCTS	PERCENTAGE OF ORIGINAL CELLULOSE	
	Yield I	Yield II
Carbonic acid	27.8 ±0.2%	27.9 ±0.3%
Residual gases	1.3 ±0.1%	1.3 ±0.1%
Water and soluble by-products	28.3 ±0.7%	27.6 ±0.7%
End-coal	43.1 ±0.4%	43.2 ±0.4%
Loss	−0.5 ±1.4%	0.0 ±1.5%
	100.0 ±1.4%	100.0 ±1.4%

under high pressure. In this process, as is well known, there occurs a combined cleavage and hydrogenation into a mixture of distillable oil and pitch in a more readily analyzed mixture. In those parts of the hydrogenation products, which boil at lower temperatures, the same substances with aromatic basis were ascertained as is characteristic in the Berginization product from natural coal. These substances were its most conspicuous parts. The aromatics and hydroaromatics, namely, are strongly enriched in fractions of 80°, 110°, 140°, 170°, 190°C. Because of this conspicuous similarity of Berginization products both from natural and from "End Coal" we are inclined to assume a similar aromatic basic structure for the artificial cellulose coal and for the natural coal. To be sure there is in this conclusion this uncertainty, that the cellulose coal during its Ber-

ginization may undergo a change of construction, but on the other hand the discovery of aromatic substances in the original "End Coal" product makes it probable that the cellulose when it was transformed into "End Coal" was aromatized.

A few words more about "End Coal" from lignin.

These experiments so far have only been made in a small way. Proportions of 150 grams of cellulose were treated with 1,000 grams of water. During these investigations, as I already reported once, much less carbonic acid was formed, only a little more than 9 per cent calculated on the original material. Accordingly the "End Coal" gained thus appeared in measurably larger quantities, i.e., more than 60.9 per cent.

The Berginization of this "End Coal" produces oil, which contains considerable quantities of aromatics, like those created by the incoaling of the cellulose. The experiments with lignin have only been made in a relatively small way because the lignin, available in larger quantities, is not sufficiently pure. We got our lignin through treating the wood with hydrochloric acid and these products doubtless underwent some change. At present we are trying to produce larger quantities of lignin of greater purity.

To return once more to our experiments with cellulose, I should like to point out how extraordinarily pronounced in those abovementioned experiments the simple stoichiometric relation between the quantities of applied cellulose and the resulting quantity of carbonic acid and water appears. One hundred parts of water-free cellulose produced 27.9 parts CO_2 and 31.6 parts water. Calculated in its molecular proportion this means that from 0.62 molecule of cellulose there came 0.63 molecule of carbonic acid and 1.2 molecules of water. Allowing for trifling errors, this proportion means the following molecular formula:

$$G_6H_{10}O_5 = CO_2 + 2H_2O + \text{"End-Coal"} + \text{by-products}$$

This simple molecular proportion may prove of importance for a further clarification of these processes.

The results of our investigations show again that the "End Coal" resulting from cellulose is very closely related to natural coal, that this "End Coal" is of an aromatic nature and that it therefore is more than likely that a considerable proportion of natural coal is derived from cellulose.

LOW TEMPERATURE CARBONIZATION OF COAL

By S. W. Parr

Professor of Applied Chemistry, University of Illinois; President of American Chemical Society

Attempts at the low temperature carbonization of coal which have been continuous and indeed cumulative as to intensity for the past 25 years seem to have attained to a number of proposed processes at the present time of about two hundred and fifty .

The normal procedure for introducing a discussion under a heading such as is used as a label for this paper would be to propose a definition. Any attempt at a definition for the low temperature carbonization of coal brings with it the feeling that such an effort would have a characteristic closely related to charity in that it must of necessity cover a multitude of sins.

Let me for the moment pass by the matter of a definition. It will be reverted to a little later after a few topics have been set forth bearing as I believe upon certain fundamental factors involved in formulating a definition.

A historical review may also be set aside even though it is an exceedingly interesting account. Especially interesting to me because my own first experiments were carried out in the early months of the year 1902, and it is generally conceded that with added years one grows reminiscent, that is to say, historically inclined. However, I am glad to note that a most admirable historical resumé has already been set forth in the book by F. M. Gentry just recently from the press and any elaboration of those facts at this time would be superfluous. I would like to address myself rather to some of the more salient factors that many investigational workers have developed up to the present time.

It seems to me that a review of the procedure and the results as they exist today show a very marked cleavage into two fundamental ideas, namely, those relating to the temperature at which the process is to be carried out. This line of cleavage is a temperature line and is drawn very closely along the zone of 450° to 500°C. (900°F.). Carbonization at temperature below this line are distinctive in behavior and in products and the attending conditions are fixed and definite and indicate in what manner and with what material the procedure may be undertaken.

Similarly, carbonization at temperatures above this line are distinctive in behavior and in products and the attending conditions yield results that are fixed and definite in character from both a physical and chemical standpoint.

These two statements regarding two distinct zones of carbonization at once suggest a reason for not attempting at the outset a definition of the term "low temperature carbonization."

Let us briefly review the behavior especially of a chemical sort in these two zones.

In the first or lower zone, as we would of course expect, the first 100° of temperature are required to drive off the free moisture and until this work is completed the temperature does not rise above 100°C. What occurs in the next 200° is of fundamental importance though it has, as a rule, been passed over by students of carbonization phenomena.

Let us take the temperature curves from any standard process, as for example, tests No. 11, 6 and 12 in the accompanying chart[1] (Fig. 1).

The indisposition of all three of these curves to rise until after a temperature of 200°C. had been passed must have some significance. If there were no other influence operating after a temperature of 100° had been reached than simple heat conductivity then these curves from and at 100° up to say 500°C. would be straight lines. Some influence is operative which tends to depress these lines and keep them below 200° and in tests 11 and 6, below 300° for a considerable length of time.

In explaining these phenomena, we are greatly assisted by data which have developed in recent years from various sources.

Note first, that up to a temperature of 300°C. the coal is still in the granular or non-pasty stage.

Second, below the pasty stage no decomposition has taken place of a sort to deliver hydrocarbon vapors. There is however, a rearrangement or condensation of organic constituents carrying hydroxyl and carboxyl groups of such a nature as to result in the splitting off of carbon dioxide and water.

Third, the resultant heat effect of these reactions over this range of temperatures is endothermic[2] in character and has substantially

[1] Reproduced from experimental data unpublished, obtained on Semet-Solvay ovens at Pittsburgh in June, 1921.

[2] Hollings and Cobb. *Trans. Chem. Soc.*, 107, page 1106 (1915).

the same effect as the absorption of heat which occurs below 100°C. in the vaporization of the free water content of the coal.

Fourth, this latent heat—we will call it "oxygen decomposition," and I believe this is an entirely proper designation for it—is affected in a decided way by the manner in which the heat is applied to the coal. In test No. 12, the thermocouple is inserted in the center of the back door, that is, at the discharge end of the oven. The application of heat here is slow and in the long-drawn out time of 11 hours the endothermic reactions have spread themselves in a fairly even

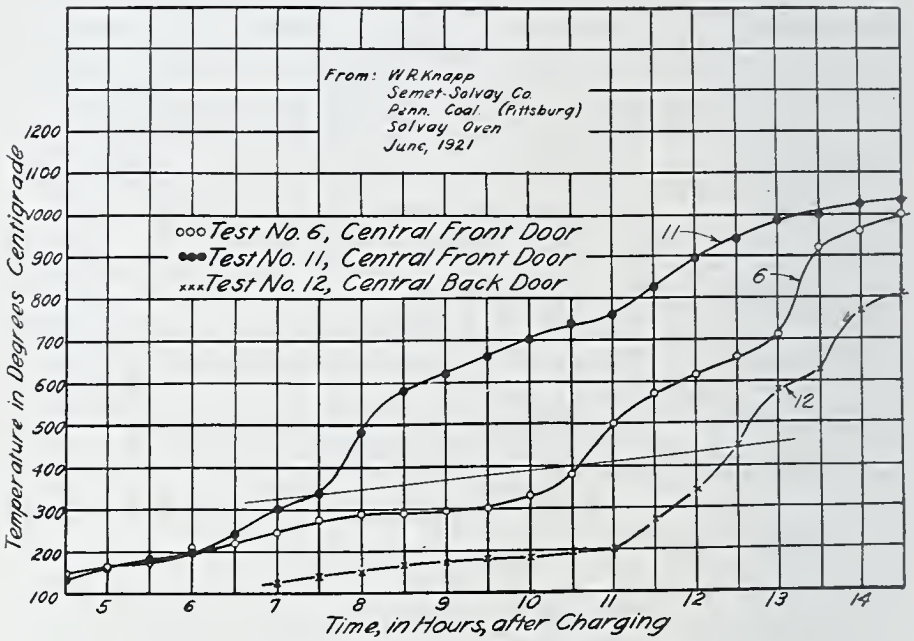

FIG. 1. TIME-TEMPERATURE CURVES FOR COAL CARBONIZATION

manner, from the seventh to the eleventh hour. From results of our own studies on other phases of the problem it is very evident that a long slow application of heat has a marked influence upon the attending reactions as also upon the subsequent reactions which occur at a further advance in temperature. This lower curve, for example, at the eleventh hour of heat application has exhausted the endothermic type of reaction and from 200° at the eleventh hour to 500°C. at twelve and one-half hours, the rise is in a straight line showing substantially only the accession of heat coming by way of conductivity due to the heat of the oven.

The middle line, test No. 6, shows a more rapid application of heat

reaching 200° in six hours instead of eleven hours, and 300° in eight hours, where the line is relatively depressed for one and one-half hours, or until the endothermic process is complete, when the normal accession of heat from the oven is alone operative for one hour, or till

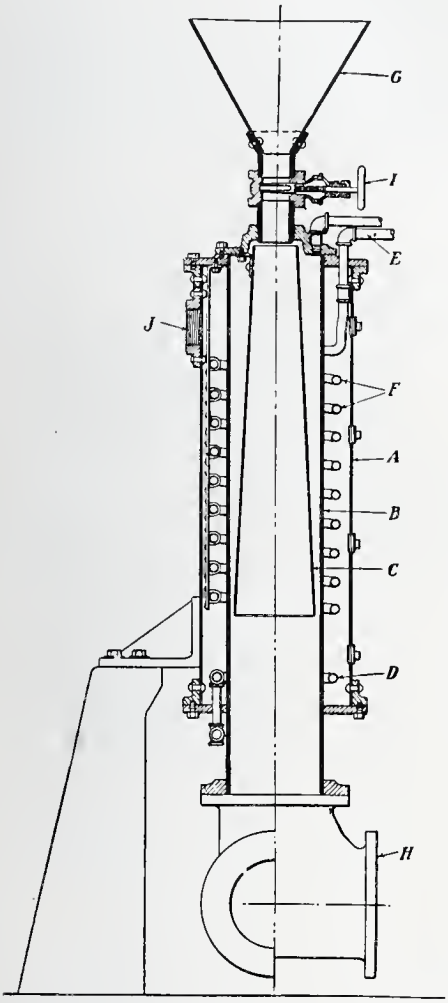

FIG. 2

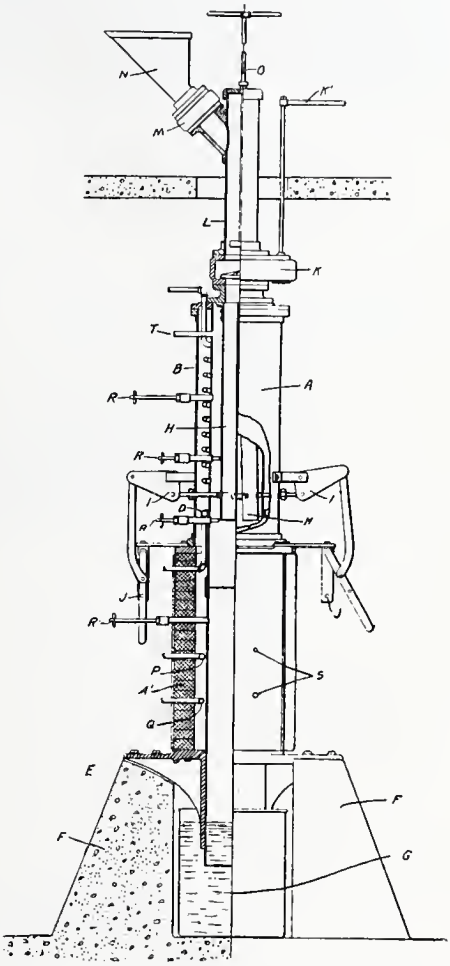

FIG. 3

FIG. 2. CROSS-SECTION OF OVEN

FIG. 3. RETORT. WALLS CAPABLE OF EXPANSION BY LEVER ACTION

a temperature of 400° is reached. We are not just now concerned with the extension of this line beyond 400°.

By reference to test No. 11 shown in the upper line we have a still more positive addition of heat reaching a temperature of 300° in

seven hours instead of eight, with a much shorter period of endothermic reactions, which again has a marked effect on the subsequent behavior, for after thirty minutes we proceed very quickly into the zone where decomposition is of the exothermic type and the products are hydrocarbons instead of the oxides of carbon.

This type of reaction is not only a function of the time required for attaining these critical temperatures but it is decidedly of more pronounced and positive character when it follows a quick accession

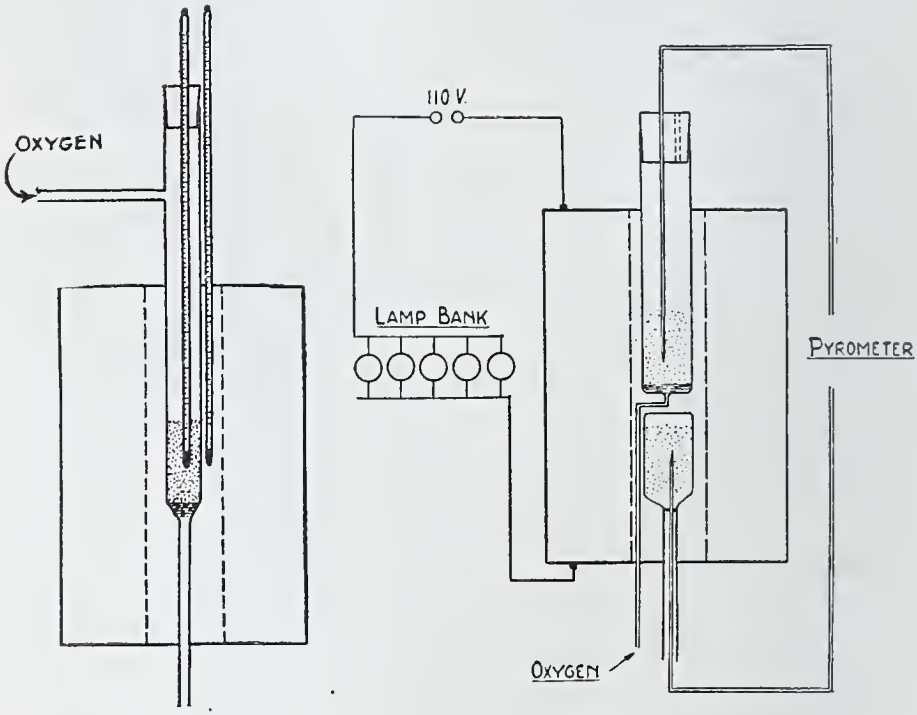

FIG. 4 FIG. 5

FIG. 4. IGNITIONAL TEMPERATURE APPARATUS FOR COAL

FIG. 5. IGNITIONAL TEMPERATURE APPARATUS FOR COKE

of heat in the lower ranges, and is far less pronounced and in fact almost annulled where the accession of heat over the endothermic range is unduly prolonged.

May I stress this point a little even at the risk of repetition?

There is nothing more positively in evidence in our own experiments than that from a very extended series of data the fact is emphasized that these reactions which occur, say below 300° to 350°, have a profound and indeed governing effect upon the reactions which

occur above 350°, that is to say, after the pasty stage has been reached, and we should further emphasize again the fact that the time factor is all important. The coal in test No. 12, after twelve hours has a behavior beyond 350° which bears no resemblance whatever to the curve for test No. 11 which has attained the same temperature after only seven and one-half hours. Indeed the zone below 300° would be very properly designated as the conditioning stage for establishing a certain chemical status from which very profound and fundamental differences in the behavior occur in the higher ranges of temperature

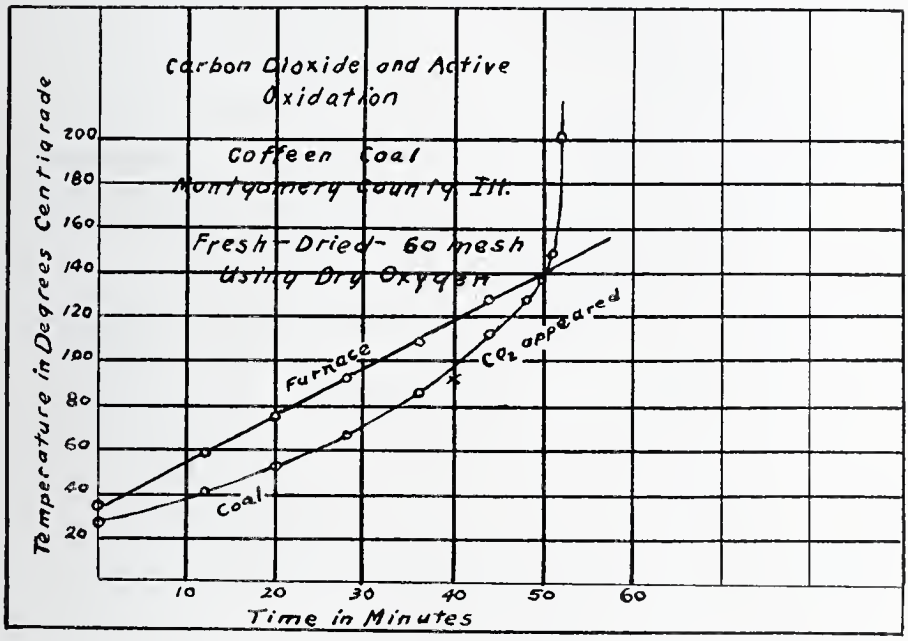

FIG. 6. TIME-TEMPERATURE. COAL FROM MONTGOMERY COUNTY, ILLINOIS

following the critical zone, which for this particular coal, from the Pennsylvania seam is at about 350°C. This time-temperature factor for bringing about certain very important chemical conditions as a basis for proceeding into the next zone is made evident by marking the points at which the resultant temperatures in each of the three tests become exothermic (Fig. 1), for example at 350° in test No. 11, at seven and one-half hours, at 400° in test No. 6, after ten and one-half hours, and at 450° in test No. 12, after twelve and one-half hours. This basic chemical condition seems indeed to be a straight line function of the time.

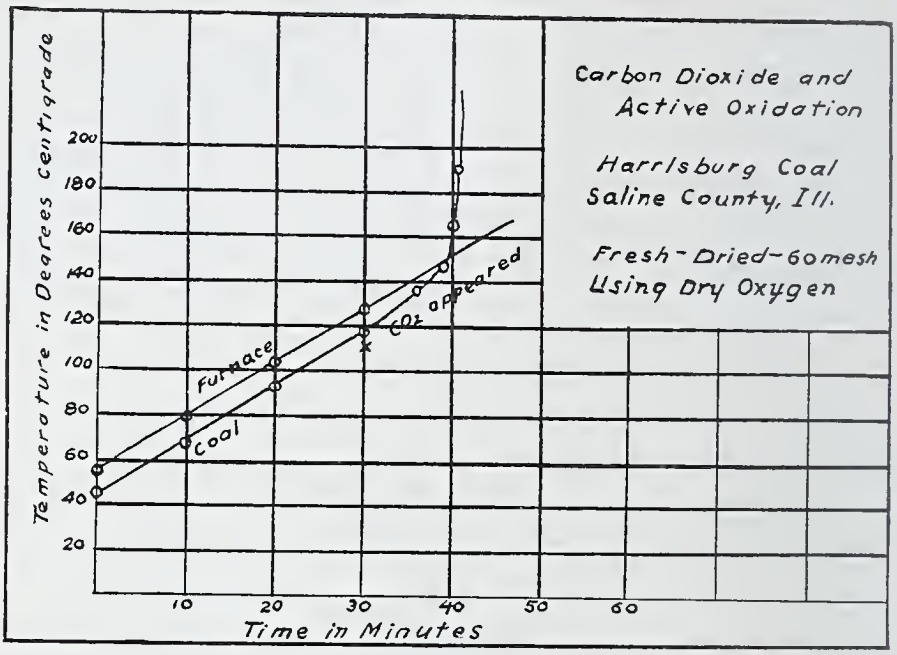

FIG. 7. TIME-TEMPERATURE CURVE. COAL FROM SALINE COUNTY, ILLINOIS

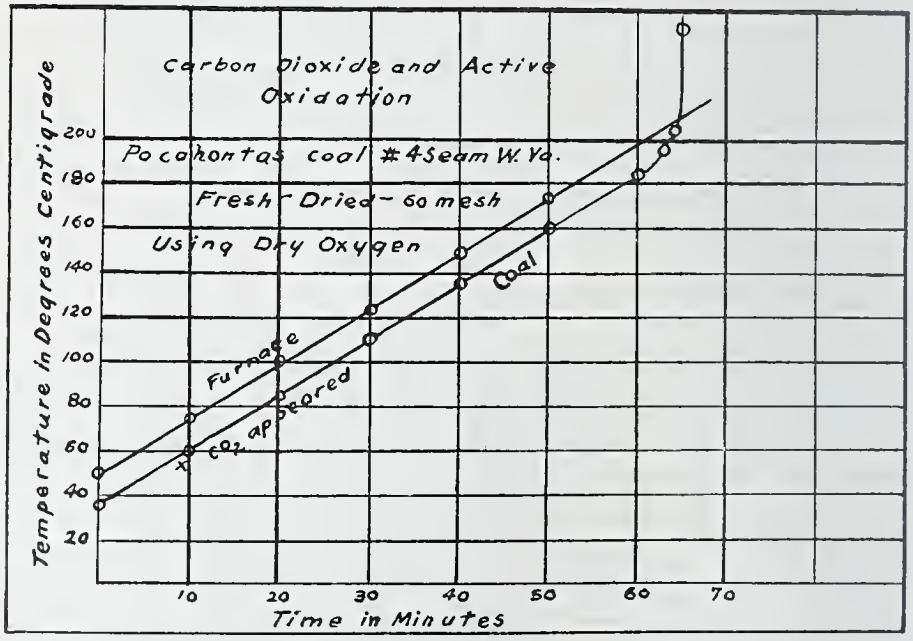

FIG. 8. TIME-TEMPERATURE CURVE. POCOHONTAS COAL

Especially also should attention be called to the pronounced character of the curves immediately following these preliminary conditions. The curve following the shortest time, that is No. 11, being sharp, positive and altogether different from either of the other two, where the conditioning period was prolonged over a much greater time.

Note one further result before leaving this chart. The ultimate temperature attained after fourteen hours, when the carbonization process has been completed differs in each case and is evidently a

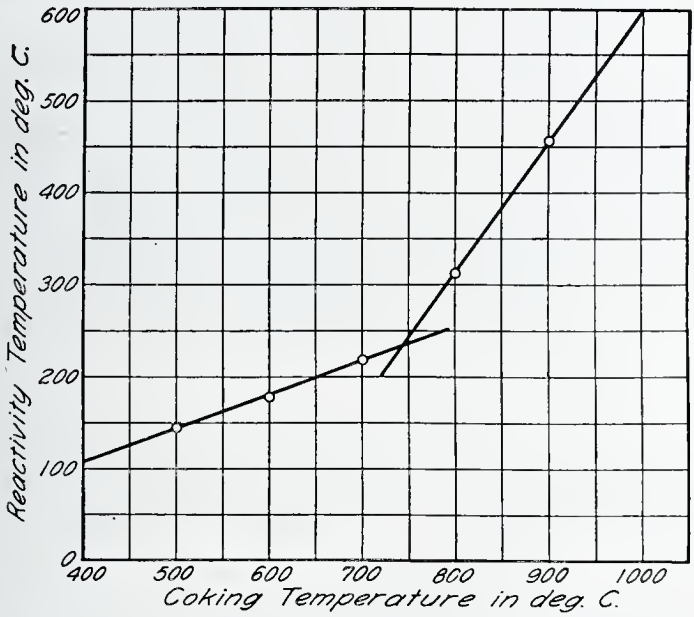

FIG. 9. SHOWING VARIATION IN THE IGNITION TEMPERATURE OF COKE AS A FUNCTION AT THE COKING TEMPERATURE

resultant from those temperature effects of an exothermic character which have been produced at and immediately following the critical stage, as at 350°; 400°; and 450°C.

We will have occasion to revert to this chart again, but for the moment we are only concerned with the results which may be attained at a temperature range not in excess of 450° or 500° C., that is, not above 900°F.

Within this range we have the usual products of tar, gas and coke, but each has its special characteristics which may be briefly enumerated as follows:

FIG. 10. PARR PROCESS EXPERIMENTAL PLANT

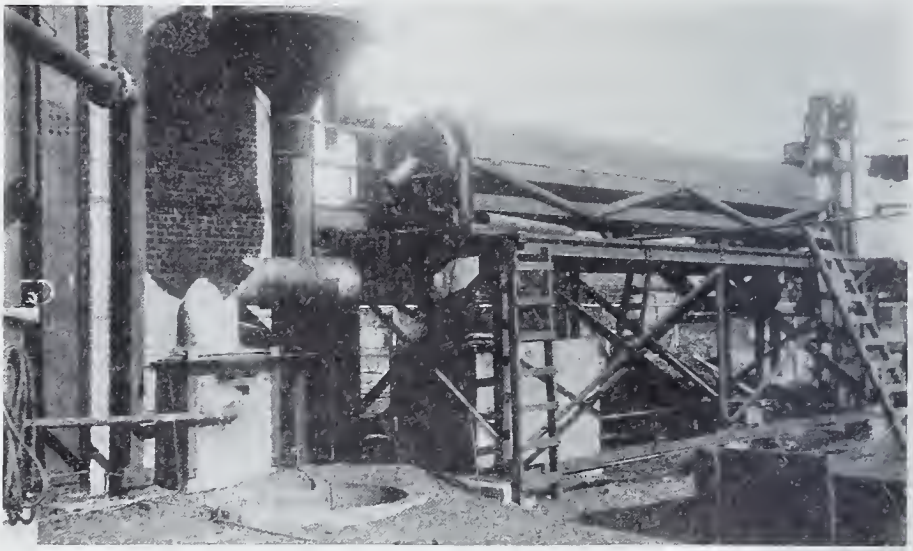

FIG. 11. THE PREHEATER FROM THE DISCHARGE END

First, the tars: These are notable with respect to the amount, the yield being from $2\frac{1}{2}$ to 3 times as great as the yield from the high

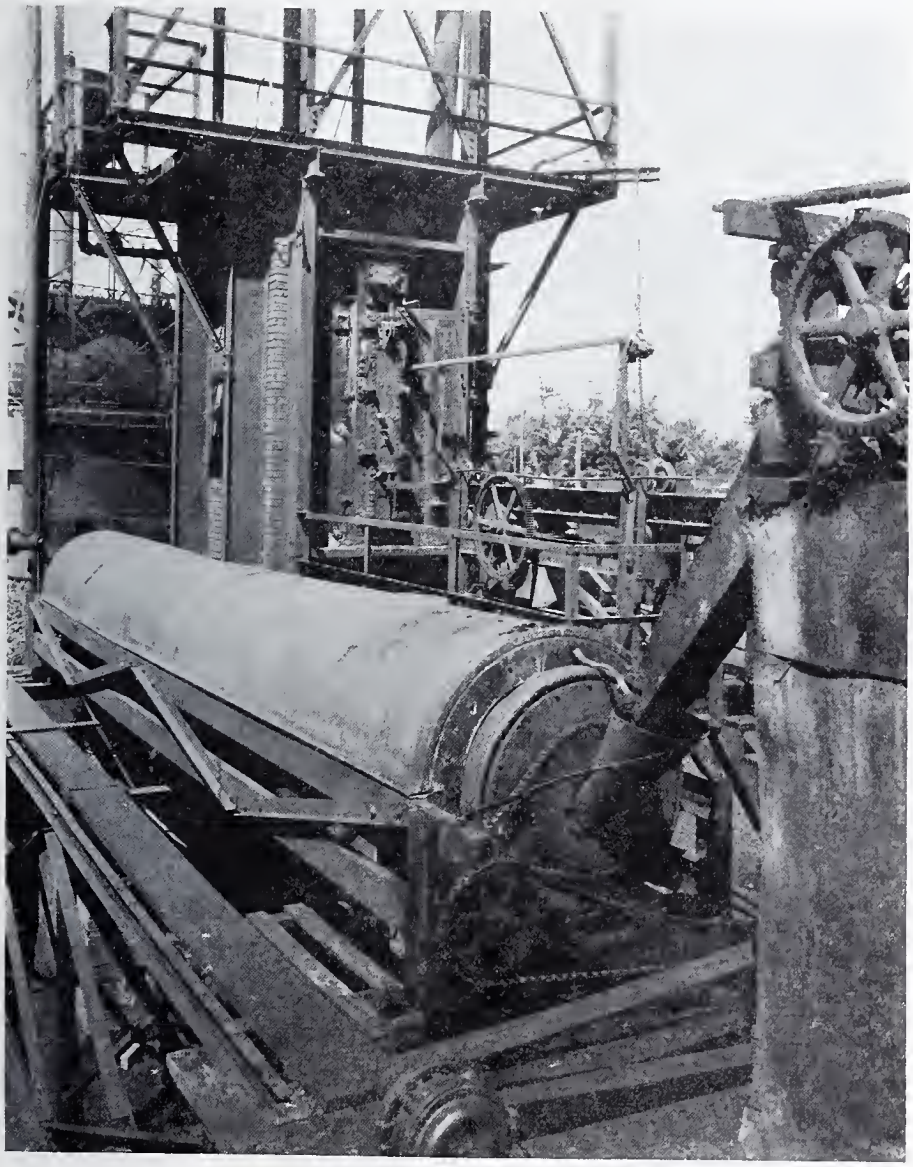

Fig. 12. The Preheater Showing Drive and Coal Feed
Pusher side of oven in center background

temperature process using the same coal. This is due to the fact that but very little secondary decomposition occurs following the primary

decomposition of the original substance which is undergoing carbonization. It is possible of course that some of the waxes or fossil resins are volatilized with little or no decomposition but for the most

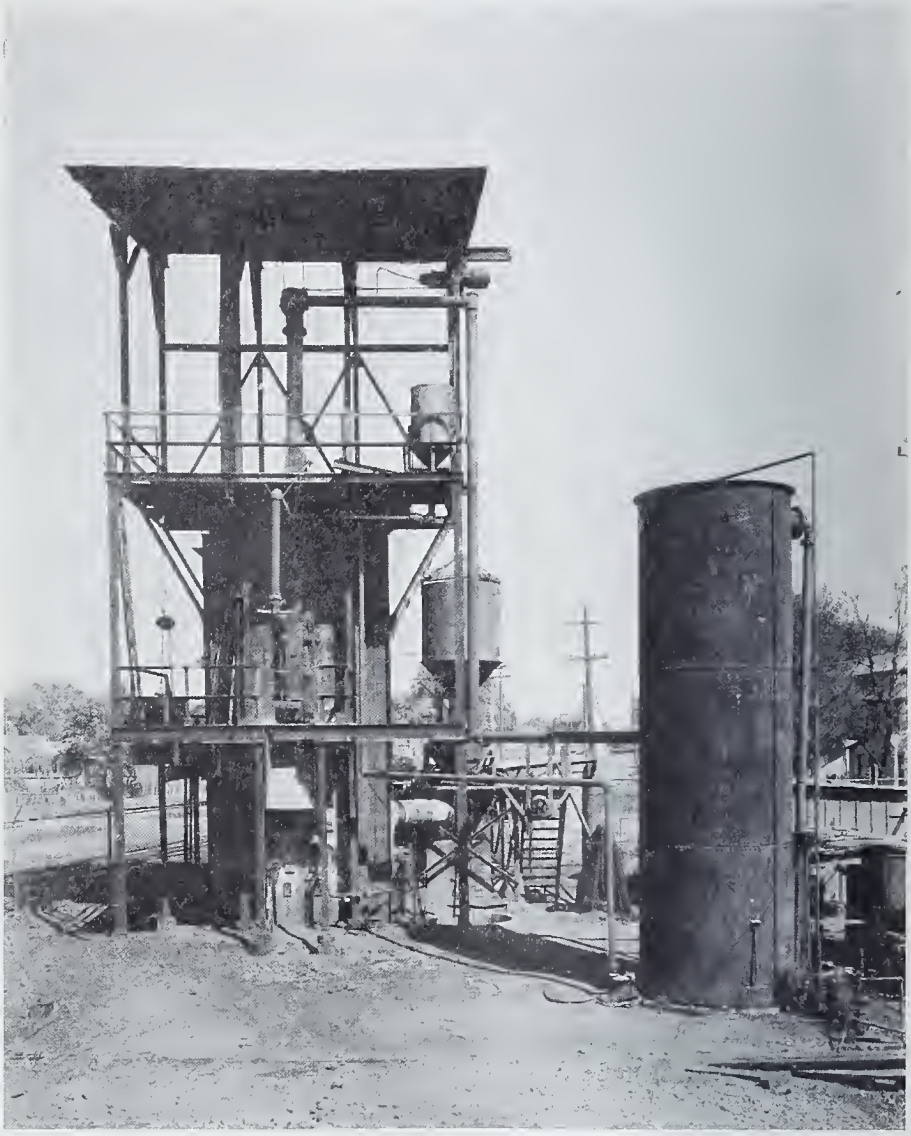

FIG. 13. PARR PROCESS EXPERIMENTAL PLANT SHOWING COKE SIDE OF OVEN

part the condensable material is the primary decomposition product resulting from the breaking down of the lignose type of organic substance which has descended by geological processes from the original

plant material. In these tars the aliphatic series of hydrocarbons predominate so that the product partakes somewhat more of the nature of petroleum oil than tars proper. This material lends itself to cracking processes under specific types of control for the production of motor spirit, lubricating or fuel or Diesel oil or hydrogen and carbon black. It would seem to have indifferent or undetermined values for application in the wood preserving industry.

Fig. 14. Parr Process Coke from Experimental Plant

Concerning the gas, its yield is small owing to the small amount of secondary decomposition taking place on the tar. The range in volume is from 3,000 to 5,000 cubic feet per ton of coal carbonized. The gas is of high heating value and may average as high as $3\frac{1}{2}$ or 4 million B. t. u. per ton, as compared with $5\frac{1}{2}$ or 6 million heat units in the case of the gas from standard processes.

The solid residue is a char or semi-coke. It is high in volatile matter averaging from 10 to 15 per cent volatile.

The limiting temperature of 500°C. is indicated for the most part

because of the metal containers within which the process is to be carried out, such heat being maintained as shall not burn out the metal. On this account, therefore, the application of the usual methods for discharging the mass at the end of the carbonization period are inoperative due to the swelling and sticking of the charge. This may be illustrated by a cross section of one of the ovens employed in our own work in Figure 2.[1]

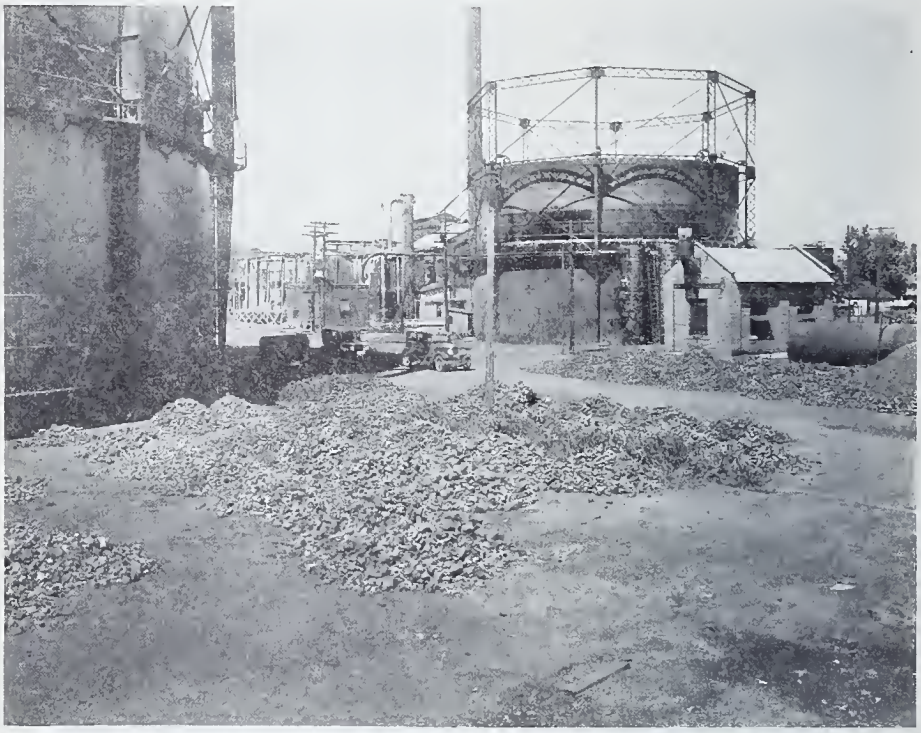

FIG. 15. PARR PROCESS COKE FROM TESTS ON VARIOUS COALS
Foreground, Illinois coal; background, Eastern coal

The charge having been subjected to the prescribed heating would not drop from the retort. The mounting of a screw pressure device and later of a pneumatic plunger were ineffective. Later the walls of the retort were made so as to be capable of expansion by lever action as in Figure 3. A similar device is seen in the modified coalite retort of Davidson in England. This general behavior of sticking in the retort has been met by numerous devices for agitating the charge

[1] Bulletin No. 60. Univ. of Ill. Eng. Exp. Sta. Parr and Olin, 1912.

while being heated, such as is found in the "Carbo-coal" process in this country and the "Fusion" process of England.

Concerning the solid material thus produced, it lends itself directly to combustion for power purposes but must be briquetted if intended for domestic consumption. Its low temperature of ignition suggests a storage hazard on account of the tendency toward spontaneous combustion unless guarded against by briquetting or otherwise.

Only such brief references have thus been made to the factors involved in low temperature carbonization as involve the fundamental principles governing the conditions prescribed. As thus considered, the definition of Gentry applies, namely, "Low temperature carbonization . . . . is taken to mean the destructive distillation of coal at or below the cracking temperature of the hydrocarbons in primary tar."

Reference has already been made to a natural or inherent line of cleavage, it being a temperature line or zone drawn at 450° or 500°C., that is, 900°F. Below this line definite conditions exist which result in definite products. I would like now to discuss briefly the conditions and the resulting products which are inherent in the range up to 750°C. or in Fahrenheit terms, up to 1,400°. And first, why a limiting temperature of 750°C.? There are a number of reasons, the most important of which will become evident upon considering for a moment the phenomenon of ignition and the temperature at which it occurs under various circumstances.

In Figure 4 for example, there is shown an apparatus for measuring the temperature of ignition for coal and, in Figure 5, for coke. Two thermometers are employed, mercurial for coal and thermocouples for coke. One thermometer measures the temperature of the oven, that is the space surrounding the coal sample, the other measuring the temperature within the sample mass. A stream of oxygen is caused to pass through the sample of coal in apparatus (Fig. 4.)

In the other device, two exactly parallel samples are used one being a blank without the stream of oxygen.

Note now a few charts (Figs. 6, 7 and 8), which show the temperature within the coal to have a lag with reference to the surrounding or oven temperature until a certain temperature effect is produced due to the combination of the oxygen with the coal. A sharp rise in temperature occurs, and the point where the coal temperature line crosses the oven temperature line is taken as the ignition point.

In Figure 6 a fresh coal sample from Montgomery County, Illinois has an ignition temperature of 140°C.

Saline County, Illinois, coal in Figure 7 has an ignition temperature of 150°C.

Pocahontas coal (Fig. 8) has about 215°C.

Using the second type of apparatus and going to coke made from the same coals, we obtain an exceedingly interesting series of results as shown in Figure 9.

Note that the ignition point of coke carbonized at 500°C. is only 148° substantially as low as the coal from which it was made.

Note also that coke made at 1,000°C. or 1,900°F. has an ignition point somewhere about or beyond 600°C., the latter temperature being the limit of the apparatus.

But especially interesting is the fact that at about 750° there seems to be an intersection of the lines representing the higher and the lower ranges of carbonization measured in terms of their ignition temperatures. It might be not inappropriate to designate this as the mid-temperature coking zone as distinct from the true low temperature zone, below 900°F. already referred to.

The question naturally arises, is carbonization at this temperature entitled to a specific recognition of this sort? My answer is very decidedly in the affirmative and while time will not permit of an elaboration of the factors involved a few salient points are given herewith:

First, coal carbonized at this temperature, 750°C. (1,400°F.), has less than 5 per cent volatile showing that the decomposition processes within the coal substance are substantially complete.

Second, the low temperature ignition point is believed to be due to the physical state of the carbon residue and not to hydrogen or methane evolved at the various points where ignition begins. It should be recalled that the ignition point for hydrogen is 300° and for methane over 600°.

Note also that sugar carbon prepared in the cold by dehydrating with concentrated sulphuric acid obeys this same general characteristic of ignition at temperatures in direct proportion to a given heat to which it has been subjected.

Third, the gas yield at this temperature is substantially all that is available at any temperature, measured in terms of heat units, that is to say for coals of the Illinois type, $5\frac{1}{2}$ to 6 million B.t.u. per ton. At higher temperatures the volume of gas may be greater, but the heat value per cubic foot will be less.

Fourth, the tars, not having been subjected to such violent second-

TABLE I

Commercial Yields Mid-temperature Coking Process

COAL	MOISTURE	VOLATILE	FIXED CARBON	ASH	COKE	TAR	GAS	GAS	
								Average per cubic feet	Total per ton
	per cent	*per cent*	*per cent*	*per cent*	*pounds per ton coal*	*gallons per ton coal*	*feet per ton coal*	*B.t.u.*	*B.t.u.*
East Kentucky—Harlan County No. 691	2.30	36.90	55.95	4.84	1,319	17.0	8,050	700	5,636,000
	Dry	37.77	57.27	4.95	1,350	17.4	8,242	700	5,769,000
Pennsylvania—Pittsburgh Seam No. 750	1.40	34.23	55.37	8.99	1,350	16.0	8,700	700	6,095,000
	Dry	34.72	56.16	9.12	1,371	16.2	8,840	700	6,180,000
Alabama—Mary Lee Seam No. 975	2.70	27.91	56.40	12.99	1,459	9.73	8,136	650	5,288,250
	Dry	28.68	57.97	13.35	1,500	10.00	8,360	650	5,435,000
Southern Illinois—Franklin County No. 1122	7.50	34.10	50.00	8.40	1,249	13.0	8,215	650	5,340,000
	Dry	36.85	54.05	9.10	1,350	14.0	8,881	650	5,773,000
Central Illinois—Vermilion County No. 883	10.20	37.00	40.80	12.00	1,153	14.2	7,833	650	5,091,660
	Dry	41.20	45.44	13.36	1,284	15.8	8,723	650	5,670,000
Indiana Fourth Vein—Vermilion County No. 634	13.42	35.00	44.77	6.81	1,125	10.4	7,305	650	4,748,910
	Dry	40.42	51.71	7.86	1,300	12.0	8,438	650	5,485,000

ary decomposition are larger in amount, more uniform in composition and of greater value due to the higher percentages of the active principles, the creosote oils, required in wood preservation. Their specific gravity is over 1.1, hence they readily separate by gravity and are drawn off as dry tar, that is with less than 3 per cent of water present.

Fifth, by strict observance of the fundamental principles already demonstrated by the temperature logs of carbonization at different rates as to time and reproducing the zonal reactions separately, the theoretical time for the actual carbonization process should be within the time limit of from $3\frac{1}{2}$ to $5\frac{1}{2}$ hours.

This can best be illustrated by referring again to the time-temperature charts already shown. For example, in Figure 1 the active process of decomposition following curve No. 11, obviously begins at 350°C. Assuming now, that the most desirable results are secured when a temperature of 750° or possibly 800° have been attained we have a time factor of 4 to $4\frac{1}{2}$ hours for the actual time of carbonization.

These conditions have been strictly observed in the experimental plant operating as shown by the illustrations following. This plant has been operating continuously 24 hours per day for 365 days. A preliminary or conditioning temperature below the softening point of the coal was regularly employed. The carbonization reactions were complete at from 750° to 800°C. and within a time limit of from 4 to 5 hours. Secondary decomposition effects on the hydrocarbon vapors were definite in behavior resulting in a gas of slightly lower volume but of substantially equivalent thermal value to that produced by the standard high temperature process. There is a corresponding increase in the condensable products, the tars proving to be remarkably uniform and of exceptionally high grade for creosoting purposes. Naphthalene formation is very slight. The coke as seen by the samples shown is dense, firm and of exceptionally high quality especially conforming in combustion properties to the ignition temperatures shown in Figure 9.

The oven employed was of standard type as manufactured by the Russell Engineering Company of St. Louis, now the Improved Equipment-Russell Engineering Corporation, New York City. The illustrations are self explanatory. Experiments were conducted on car lots of coal from as far west as Iowa, as far south as Birmingham, Alabama, and from the Pittsburgh and Cambria County seams in the East with substantially all type from Eastern and Western Kentucky, Indiana, and Illinois. Without exception a high-grade coke was produced. Typical examples showing the amount and character of the yields are given in Table I.

CARBON, HYDROGEN AND CAPITAL

By F. zur Nedden, M.E.

Secretary, Fuel Committee of Reichskohlenrat, Berlin

On the occasion of a conference such as this it might not be out of place to try to get some broad perspective of the general economic development with regard to coal, and which, indeed, this whole conference is serving.

In trying to judge the general trend of any given development it is always advisable to consider long periods of time and large economic units, decades and countries,—if possible, centuries and continents.

Professor W. T. Page has enabled us by a splendid "Memorandum on Coal" which he submitted to the World's Economic Conference of the League of Nations last year[1] to look back upon half a century of development in the United States using the quinquennial period that the Romans termed a "lustrum," as a unit of time. I have put his figures into the shape of a diagram (Fig. 1).

The diagram illustrates the trend of technical and economic developments. The trend is towards diminishing the relative importance of coal, a rather cumbersome compound of hydrocarbons fraught with heavy weight and a ballast of ash and humidity, and favors the consumption of such hydrocarbons as oil and gas. These can be pumped, they show great purity and a high concentration of energy per unit of weight. Consequently they lend themselves to cheap transportation, ease of regulation and concentrated production of energy. At the same time the diagram also shows that the use of coal is far from being discarded. Consumption of coal is still increasing.

If, on the other hand, we consider Europe, Goethe's prophecy applies:

"America, thou farest better . . . . "

While "God's own country" is able simply to fall back upon its huge natural stores of resources in the shape of natural oil and gas, Europe is poor in natural oil and almost without natural gas. The development in a typical country, such as my own, Germany, therefore, shows a different aspect from that in the U. S. A.

[1] Document C. E. I. 18, Vol. 1, p. 52, of the Worlds Economic Conference, published by the League of Nations, Geneva, 1927.

Unfortunately I am unable to show you as comprehensive a picture for Germany as Professor Page could for America, because our statistics are not quite up to yours. Still, this diagram (Fig. 2) gives an outlook for a period of three *lustra*, and at any rate will show this: While fifteen years ago 52 per cent of all coal mined in Germany went to the ultimate consumer of energy in raw state (possibly cleaned or washed), that percentage has diminished to scarcely more than 40 per cent in 1928. While the transportation of coal in the shape of electric power is partly responsible for this change, yet the strips indicating pulverization and low temperature

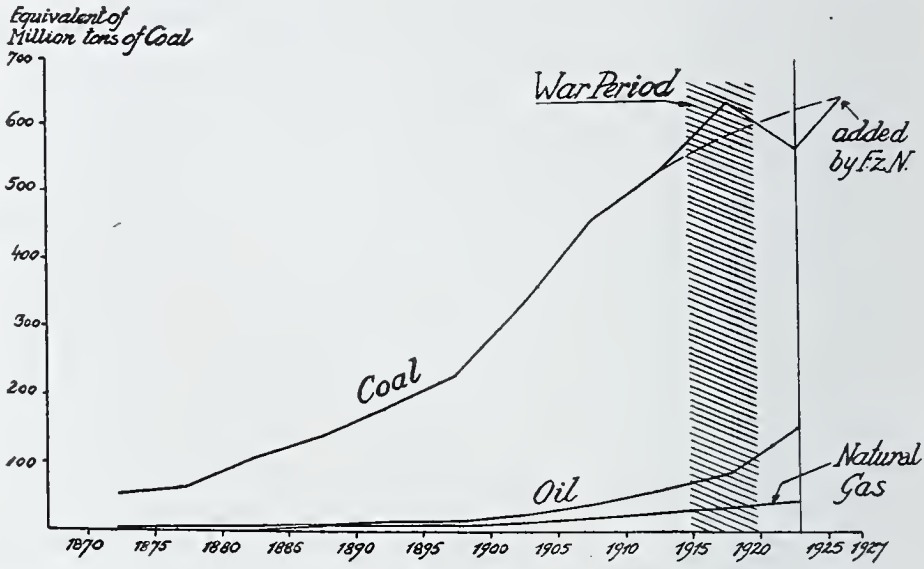

FIG. 1. ANNUAL CONSUMPTION IN THE UNITED STATES OF COAL, OIL, AND NATURAL GAS, IN QUINQUENNIAL AVERAGES
(According to W. T. Page)

carbonization have appeared and have broadened out in the diagram for 1928. The ribbon showing the percentage of coal transformed into oil by *hydrogenation*, slender as it yet may be, seems as important as a new ribbon in the spectrum may be to the exploring physicist, for it heralds the advent of a new ally to coal, hydrogen, which bids fair to protect Old King Coal from being subdued by his mighty rival, oil.

Figure 2 should show clearly enough that European countries are forced by technical development to travel the same road in principle as the United States, namely, from raw and cumbersome hydro-

carbons to refined hydrocarbons and electric power transmission. However, as nature has not endowed us with that abundance of liquid

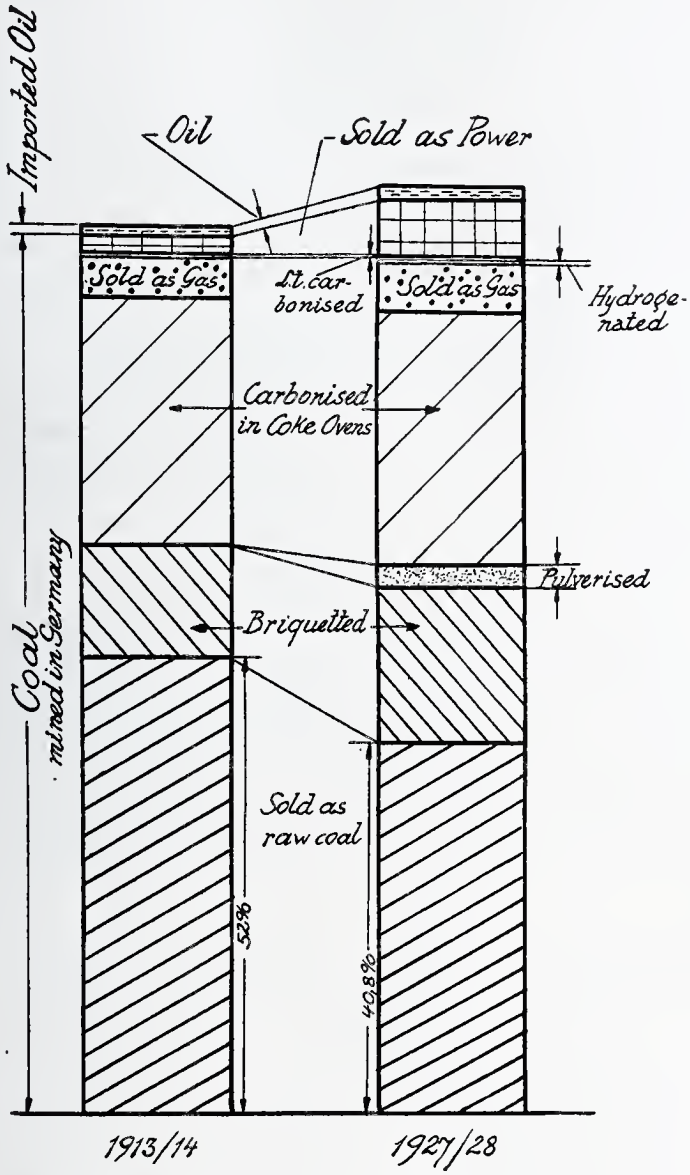

FIG. 2. RATE OF INCREASE IN COAL IMPROVEMENT IN GERMANY 1913 TO 1928

and gaseous hydrocarbons springing forth from our soil, we have had to replace nature's favors by science and hard work, and we have had to introduce all sorts of methods to increase the form value of

coal by such means as hydrogenation, low temperature carbonization, long distance supply of coke oven gas, etc.

We have a proverb in Germany: "Emergency makes inventive"; your equivalent is "Necessity is the mother of Invention." Europe had the great good fortune of giving birth to such men as Berthelot, Claude and Patart in France, Casale in Italy, and Bergius, Mittasch and Fischer in Germany. These men taught us how to add to coal artificially that which it lacks in hydrogen in order to transform it into refined hydrocarbons, such as alcohol, gasoline or rich gas. Also all processes of "improving" coal, either mechanically by cleaning, blending, pulverizing or briquetting, or chemically by carbonizing or hydrogenating, or, last but not least, by transforming it cheaply into that most sublime form of energy, electricity,—all these processes of "coal improvement" have thrived in Europe because of the necessity of supplying a substitute for natural gas, and of supplementing the natural oil supplies and the water powers of nature.

Science became a form of capital to us quite as important as the monetary form of capital, as Dr. Baker so aptly expressed it in his address at the First International Conference on Bituminous Coal in 1926. While America invested a majority of its capital for the production of power in sinking boreholes and harnessing the forces of waterfalls, we had, and still have, to invest a majority of our capital in factories for the improvement of coal and in thermal power stations. In Germany these supply 88 per cent of all electricity, while in the United States the percentage is but 62 per cent.

Figure 3 will serve to illustrate the result of this combination of science and capital with regard to coal. In this diagram I have illustrated the amount of capital investment tied up in the transformation of $5 worth, or roughly 1 ton of high grade bituminous coal per annum. Of course this had to be done in a rather crude way, taking broad averages only, and closing one eye to get broad outlines and avoid variations in detail which might distract attention from the general view. The area of the hatched square at the lower left hand corner of the diagram indicates the value of $5 in the shape of coal, the areas of the various rectangles show, on the same scale, the amount of capital invested in the various kinds of plant required for improving the quality of this amount of coal, and incidentally the monetary value, of the energy contained in this coal.

These rectangles are based on abscissae representing the rate of increase in value which the products of improvement represent in comparison with the value of the raw coal from which they are won. For example, a boiler plant transforming annually 1,000 tons of coal valued at $5 per ton may cost about $10,000, and produce when operated for ten hours each working day, i.e., under a load factor of about 33 per cent about 8,000 tons of steam worth $1 a ton. Then the value of the energy derived from one ton of coal, viz., 8 tons of steam, will be $8, or the energy of coal will have been improved in the proportion of 8 to 5, that is, 1.6 (abscissa on Figure 3),—and the capital investment per ton of coal put through the

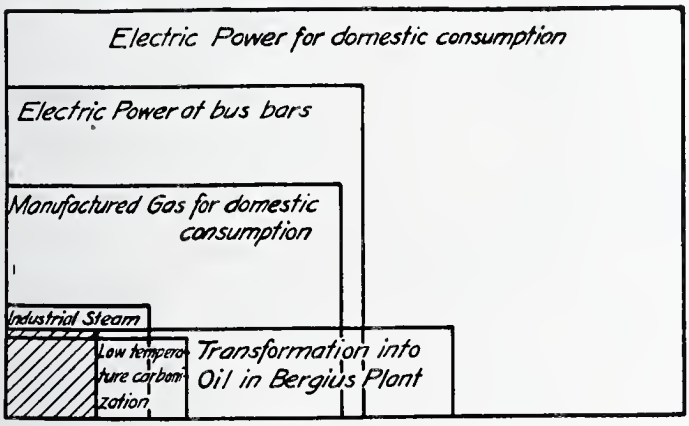

FIG. 3. CAPITAL INVESTMENT REQUIRED FOR EACH $5 WORTH (HATCHED SQUARE) OF ANNUAL THROUGHPUT OF COAL COMPARED WITH THE INCREMENT IN VALUE (ABSCISSAE) OF ORIGINAL COAL WHICH THE PRODUCTS OF COAL IMPROVEMENT REPRESENT

plant per annum will be $10,000 divided by 1,000 tons, or $10 per ton of annual throughput of coal (area marked "Industrial Steam" on Fig. 3).

I am not going to bother you with the details of calculating the table on which Figure 3 was based, nor would I be surprised if in adapting this European diagram to American values you should find one or the other area or abscissa to be somewhat larger or smaller, longer or shorter in America than in Europe. At all events, you will agree with this diagram in principle in so far as it is essential for establishing the following rule: *The higher the quality of the bearer of energy into which you transform coal the greater is the amount of capital which you must invest per ton of annual throughput.* (This

capital is represented by machinery and apparatus by which the coal is transformed.)

Incidentally I may draw your attention to two facts:

1. When considering the area which represents the capital investment per ton of coal annually transformed into electricity at the bus bars of the power station, and comparing it with the area representing the amount necessary to put this energy at the disposal of the ultimate consumer of light and domestic power, you will see that the amounts are individually very large. You will further see that the difference between these areas is very large. This difference represents the investment of capital necessary for the *distribution* of the energy from the bus bar to the ultimate consumer. This would indicate that technical progress applied to diminishing the amount of coal required to produce electricity is of less importance economically than any efforts that may be made to reduce the high *capital* investment required for the generation, and particularly *distribution*, of electric energy.

2. When you compare the general shape of the rectangles representing the processes to improve coal as it is given us by nature with the rectangle representing the transformation of coal into oil by means of hydrogenation, you will see that the latter is flat while the former are high. This indicates the favorable effect of the high load factor of chemical coal improvement where the plants are busy practically uninterruptedly at least 7,000 hours out of the 8,760 hours of the year. In consequence, the capital investment per multiple of increment of value of the product is relatively small for such a chemical plant. Although this may be in itself a large sum, relatively more capital must be invested in plants which are operated intermittently or with a poor load factor. In other words, capital invested in chemical plants for adding hydrogen to carbon will enjoy a better annual turnover than capital invested in power stations.

(It may be noted in passing that low temperature carbonization in successful plants also requires but a relatively modest investment as compared with the increment in the value of the products over the value of the coal carbonized.)

A lot more may be deduced from diagrams built upon this principle, especially when it will have been possible to refine them by the aid of more detailed figures and statistics. But I think that the speaker should not do all the thinking. He should leave some for his hearers to do.

However, if you will kindly listen to me for a few more minutes I may say that these cogitations are just a little bit more than mere philosophy, and that they may concern Americans just as much as they do us Europeans. Otherwise I should feel that I had no right to come across the Ocean to take part in this conference.

I may point out that all these processes for improving coal by enhancing the value of the energy contained therein were built up on coal, notwithstanding the fact that such improved form of energy is often offered by nature ready made. This is especially true of the United States where manufactured gas is sold in larger quantities than in any other country of the world, both in total production and in production per inhabitant, in spite of the fact that natural gas offers much competition; and where approximately two-thirds of the electrical energy generated is generated from coal, in spite of the fact that the country is richer in water power than almost any other country of the world.

Therefore the new possibilities of coal, such as the manufacture of synthetic fertilizer, synthetic alcohol and synthetic gasolene, will prove hardly less attractive for this continent blessed with fertile soil and natural saltpeter, with wood for making alcohol and with petroleum surging from the earth, than they are for Europe. I venture to say that the processes of chemically adding hydrogen to the natural hydrocarbons as contained in coal and petroleum will be attractive to the American financier and business man, in spite of the fact that he is wading in natural oil. It may, however, be necessary to adopt a form modified to the particular American requirements such as, for instance, the combination of hydrogenation with the cracking processes.

Aside from these considerations a few further words may be said which would appear to be of *international* interest.

It is becoming more and more apparent that in many fields of industry we are approaching that limit of production which is set by the capacity of man to consume goods, and where goods are produced not because the world is in need of them, but because the producers have to diminish the costs of production by a large turnover. If, as many economists seem to believe, it were a question merely of selling *quantities*, then industrial production would be limited by the possibilities either of enabling the consumers within the country to consume *more* goods, or of opening more export markets.

Now the story of carbon, hydrogen and capital seems particularly

well suited to illustrate the fallacy of that one-sided *quantitative* way of looking upon developments. This story clearly shows a way of progress both in quantity *and in quality.* Energy is thus at the disposal of man in more and more improved quality, and this is being done by intertwining more and more technical processes between the raw coal and the ultimate product offered to the consumer. These processes are tying up more and more capital per unit of raw material—in this case coal.

Capital may be characterized as frozen wages. When tracing the formation of capital to its ultimate source we nearly always find that it springs from the surplus of wages over immediate consumption. When capital is invested, i.e., when plants are built, it melts into wages again. It is a source of gainful occupation, not only to the man operating and building the plant and all its paraphernalia, but also indirectly to all men occupied in the industries providing the materials from which buildings, machines and apparatus are made.

Coal improvement has a very decided tendency to occupy capital, and thereby stimulate and fertilize the whole fabric of industry. More and more, coal and the products manufactured therefrom will not only provide the world with the energies on which the age of machinery is dependent, but also will create for industry huge and profitable markets. Coal improvement is, therefore, enlarging the limits of industrial productive capacity. Similar examples are to be found in the replacement of the horse and buggy by the automobile, or the replacement of heavy woolen stockings by feather weight silk hose. Supplying goods of higher quality has invariably created whole industries for improving raw materials.

Certainly there may be and there always will be many ways whereby capital can be made to revolve more rapidly than by investing it in plants for coal improvement, for carbonization, power production and hydrogenation of coal and oil,—yet here is one side to this particular kind of investment which gives it a very great importance. As the supply of energy in all its various forms, which are constantly becoming more refined, is the basis of modern civilization and industry, it always requires long-term foresight so that the building of plants for the improvement of coal is more or less a matter independent of the fluctuations of business trends. This kind of investment, therefore, acts as a *stabilizer* ironing out the fluctuations in the occupation of industry and labor and as a stabilizer also for the coal industry itself. It affords the same advantages to the

community and to the coal industry that a good base load offers to a power station.

I think that this is a direction of thought along which it will pay the economist and financier to engage in analysis and research. This offers very practical and gainful ends, especially to the American financier who has become the banker and "the trustee of the frozen wages" of the world. At any rate, I hope that you will share with me the impression that there is much in this story of carbon, hydrogen and capital which have contributed to this gathering of experts on coal. It does not sound like the tragedy of coal, but rather a new triumph of coal: "coal improvement."

THE SYNTHETIC KINGDOM

By Edwin E. Slosson

Director, Science Service, Washington

The last remnant of Latin learning to linger in the mind of any man is the first sentence of the first book he ever read in the language "All Gaul is divided into three parts." A similar bit of our childhood beliefs that we retain is that all nature is divided into three parts—animal, mineral and vegetable. There was a game I used to play as a child—I do not know that it is played nowadays by anybody—called "The Game of Twenty Questions." In this one person selected mentally a certain object and it was the aim of the rest to find out what it was in no more than twenty questions. The first question, which was as stereotyped a move as the King's pawn in chess, was "Is it animal, mineral or vegetable?" for this at once divided the field of the universe into three sections and so reduced the area in which the unknown object was concealed. But this traditional tripartite partition has been abolished by the introduction of synthetic chemistry, for now a large and increasing number of objects in daily use bear no traces of their origin in vegetables, animals or minerals, and, in fact, might be derived from any one of them without our knowing which. We must then admit the existence of a fourth kingdom, not a kingdom of nature but transcending the natural kingdoms. In this must be included the products of synthetic chemistry and all those natural materials that have been so fundamentally altered in the process of manufacture as to lose all allegiance to their source.

This fourth kingdom is preëminently the kingdom of man since it is the creation of the human mind and comes from the conquest of nature. It was just a hundred years ago since the chemical Columbus made his memorable voyage into the undiscovered kingdom of vitalism and overthrew the pretender who reigned there *vis vitalis*. As Columbus, setting out to reach Asia by sailing westward across the Atlantic, found that he had unconsciously invaded a new continent, so Friedrich Woehler at the age of twenty-eight, in trying to make an inorganic salt (ammonium cyanate) from an inorganic acid and an inorganic base, found that he had unconsciously invaded the organic realm and got instead urea.

In the century since then progress in the development of this new

continent has been so rapid that already its population outnumbers that of the two ancient kingdoms of animal and vegetable life. The latest edition of Beilstein's Dictionary contains 400,000 compounds of carbon of which only a very small proportion are to be found ready formed anywhere in the three kingdoms of nature.

The financial, industrial and political consequences of the rise of the Synthetic Kingdom are already immense and in the future immeasurable. Where the same compound can be made from various sources it destroys the monopoly of localized materials. For permanent local monopoly the chemical industry substitutes limited international monopoly by patents. But however impregnable may be the patent and however close the trade secrets are kept, all such individualistic knowledge finds itself away ultimately into the open sea of science as all rivers run into the ocean.

Another characteristic of the chemical industry is scientific control. A live laboratory is essential for a thriving industry, affording a field to the most inventive genius and most skilful craftsman. A chemical plant also provides a place for the lowest intellect and most inert individual among its employees since its routine processes are mostly mechanical and require little skilled handicraft.

The Synthetic Kingdom requires men of more intelligence and higher training than do the earlier industries. To raise cotton and to pick it is a task within the capacity of the humblest agriculturist. To make celanese and to spin it is a delicate operation. It is easy for the amateur to convert carbohydrates into ethyl hydroxide by the aid of Saccharomyces cerevisiae, as many of our fellow citizens have found out for themselves by personal experimentation during the last ten years. But to convert carbohydrates into butyl hydroxide by the aid of Clostridium butylicum requires the constant control of skilled bacteriologists. Otherwise the lactic acid bug is liable to get the start, crowd out the butyl bug, and shut down the works for months in the busy season. It takes all sorts of people to make a world and all of them can find employment in a chemical factory.

The ramifications of chemical industry spread with little regard to the parti-colored patches placed on the maps by patriotic politicians. When I look at a map of the coalfields of Pennsylvania I see that the beds do not conform to county lines, but underlie larger areas which cannot be defined in political terms. Evidently the boundaries of the forests of the Carboniferous Era were not laid out by the state

surveyor. So when I trace the connections and combinations of the chemical industries throughout the world, though this is not so easy for the underground workings of financial geology are not published on maps, it nevertheless is evident that these aggregations of chemical capital and correlations of chemical control are not limited by national lines.

The Synthetic Kingdom underlies the kingdom of politics, as the coalfields underlie the artificial administrative divisions. Chemical industry may be limited in expansion by national organizations, or may take advantage of them for internal development, but essentially the Chemical Kingdom obeys its own laws which are not of the kind devised by lawyers. Although chemistry is an artificial thing it grows like a living being. Like a tree, for instance, for when a writer wants to show on a chart the development of an industry like coal-tar or rubber, he instinctively plots its ramifications in the form of a tree.

One of the unique advantages of the Synthetic Kingdom is its flexibility. Minerals remain unaltered in the earth for millions of years. Plants and animals undergo gradual changes in the course of ages and although the horticulturist and the animal breeder have succeeded in recent years in speeding up the process of evolution, he is not yet able to turn out to order any particular form of plant or animal that may be needed at the moment.

But in the Synthetic Kingdom man is the monarch and can guide its operations with marvelous facility. The adaptability of the chemical industry is one of its most novel and conspicuous features. It reminds one of the change in transportation that is taking place before our eyes. The reason why the motor bus is proving to be such a strong competitor of the trolley car is largely because of its adaptability. The dispatcher says to the bus driver when he starts out in the morning "14th Street is blocked by mending pavement. Detour down 16th Street today." But a street car cannot shift to 16th without a new franchise, right-of-way, private permits, excavating streets, and laying tracks, processes that take years instead of two minutes. Shifts are as easy as this in the modern chemical industry. Suppose, for instance, the boss of a textile factory gets a cable from his spy, a keen-eyed stylish looking lady at Deauville, that the modish dresses at the races today show an inclination to less shiny silks and stronger shades. He simply telephones down to the works and orders the foreman to delusterize the cellulose acetate

filaments by boiling them in a soap solution and to intensify the color by adding another nitro group to the dye. In former times the textile manufacturer could only have effected such an alteration in his cloth by shipping his silk from another country or ordering a different dye stuff from the tropics. Perhaps he could not have accomplished the desired alteration without forcing the Asiatic or African native to alter the habits of his ancestors for centuries. Now the chemist can change his color as quickly as a woman can change her mind. This is an amazing achievement in celerity for industry.

In conservative countries costumes have remained unaltered in texture and tint for thousands of years. We are apt to ascribe this tenacity of habit to indolence or inertness. But it may be questioned whether this is an innate and racial characteristic or whether the conservatism of mankind has been imposed by conditions. We are apt to regard as natural a characteristic that is due to constraint.

The peasant could not change the color of his garments any more that the Ethiopian his skin. Having in most cases only a single dye he can only vary it in shade. He had only the choice that is offered you in a helping of chicken, will you take light or dark? The gorgeous and sometimes garish colors that we see today in feminine costume may not be due to any sudden eruption of a polychromatic propensity in feminine disposition but simply to the possibility of the gratification of a desire for gay colors that has been suppressed since the days of Eve. Since dyes of all hues of the rainbow and many not found there can be purchased at the corner drug store for 10 cents a package the feminine mind can for the first time in all ages show itself in its true colors.

I am aware that I am using the word "synthetic" here in a wide and loose sense, but there is really no word correctly to cover what I have in mind—those substances that have been so transmogrified by the chemist as to be altogether different from their natural form. The class ought to include all such things as iron and glass, although these have been known so long the world forgets that we owe them to chemical manipulation. An old lady belonging to one of the stricter sects of Pennsylvania protested against the introduction of stained glass into the church. Her scruples were overruled by the younger generation and the glass put in. Then she was asked if she did not like the looks of the windows. "Yes," she conceded, "they look pretty, but as for me I prefer the glass the way God made it." No one has a right to laugh at this old lady unless he has himself never felt a like reluctance to welcome a novel and artificial product.

When I speak of this new field of chemical industry as the Synthetic Kingdom I have in mind something more than the mere fact that it consists in making new combinations of the chemical elements. It also makes new combinations of industries and brings together different countries as well as chemical elements. As the Synthetic Kingdom overrides the traditional dividing lines between animal, mineral and vegetable, so also it overrides the traditional boundary lines between the nations. It brings international competition which naturally results in the end in international coöperation. This modern development of chemistry has strong political consequences. It promotes national independence and at the same time breaks down natural monopoly. Twenty years ago it could be said that Chile had a natural monopoly of the world supply of nitrates but that monopoly has been broken in two ways; by the utilization of the nitrogen from coal through the preservation of its by-products, and by the utilization of the nitrogen of the air through fixation. An impartial Providence has endowed every nation with a supply of nitrogen exactly proportional to its area. Whether this free nitrogen is utilized or not in any particular country depends not upon natural resources but upon the ability of its people. Brain power, like water power and coal power, is very unevenly distributed among the nations.

The effect of the synthetic regime in short circuiting natural processes and multiplying the resources of raw materials has brought industries and countries into unexpected competition. The chemist has upset the geography that we learned in school, for when we were children the natural products were duly distributed among various countries by what was assumed to be the immutable law of nature. To impress this upon our youthful minds we had pictorial maps showing the sources of the substances that were consumed in our daily life: a rubber tree in Brazil; an indigo plant in India; a cotton plant in Carolina; a camphor shrub in Japan; and a silk worm in China. The chemist has ruthlessly uprooted these neat emblematic labels. The United States may ship indigo to India. If the motion picture magnate finds that Japan is charging him too much for the camphor for his films he may buy it from Germany where it is made from American turpentine. The silkworm of Japan and the cotton plant of Carolina are hard pushed by the competition of the wood pulp of Sweden.

The realm of the carbon compounds is world-wide since the

elements are those of air and water. Such imitations of the synthetic domain as now exist are due to our ignorance. Quinine is still made from Peruvian bark and morphine from the poppy plant. The automobile industry is yet dependent for sustenance upon the milk of the rubber tree, although recent progress in colloid chemistry gives promise that it will ultimately be weaned. Since coal and oil are easily obtainable in any country and since cellulose can be grown anywhere except in the polar regions, there is no serious shortage of supply of carbon as a crude material. This unfortunately is not the case with the metals which have been capriciously allotted by nature to the various nations and there is no probability of their transmutation by practical processes. This is likely to be the first setback to the expansion of civilization because we are extracting such elements as tin, lead, copper, gold, platinum, chromium, manganese and mercury, from the particular places where they are found most freely, and after using them we are scattering them so widely as to be forever irrecoverable. Even iron, one of the commonest of the elements, is rarely found in such rich deposits as those that we are now exploiting so extravagantly.

Carbon, which is the fundamental element of all forms of life and one upon which our modern civilization is peculiarly dependent, is, strange to say, one of the rare elements of the world. Carbon constitutes only 0.04 per cent of the elements composing the earth. In the list of earthly elements it stands at the very bottom with the exception of titanium; almost too small indeed to be included in the analyses.

Yet thisel ement, one of the least in the list, has been sole sovereign of the world for a thousand million years due to its unique capacity to form the framework of living protoplasm. It has also during the last 150 years become the chief promoter of civilization because of its capability as the condenser and carrier of solar energy. Coal is the storage battery of modern industry. Of course modern civilization has its critics as well as its admirers. A professor in a German theological faculty not many years ago explained the alarming decline of public morals by saying that when God separated light from darkness on the second day of creation he buried the darkness in condensed form in the bowels of the earth, but now men have incautiously lifted the lid from the coal beds and the darkness thus released from prison has generated and set free all manner of devilish lusts like drunkenness and debauchery. This is a new argument for

coal conservation; it is not safe to mine it faster than it can be consumed. But I should regard coal, on the contrary, as stored sunshine rather than stored darkness. The unprecedented prosperity of the present time is due to the sudden release of the accumulated savings of the energy received from the sun 250,000,000 years ago.

Science in its infancy was called "natural history." It was a good name for it—then, but highly inappropriate now. For the scientist in those days could do nothing but observe and record what occurred in nature in the same way as the historian of human affairs observed and recorded the doings of men. Neither of the historians dreamed of altering the course of events to suit themselves. When the historian set down the words "Caesar was slain by Brutus" he may have sighed: "How sad!" but it did not occur to him to add: "Let me see if I can't reverse that and have Caesar slay Brutus." So too when the chemist of the seventeenth century wrote down that "Cloth is colored blue by a dye made from a plant that grows in India," it did not occur to him to say to himself, "Why can't I make it from English coal?"

But to the modern chemist that is the first thought. When he hears of a useful natural product he sets to work at once to make a better one. If he learns that chaulmoogra oil from some unknown Asiatic tree has a good effect upon leprosy but is dangerous to take, he promptly improves upon it. Nowadays he does not even wait for a hint from nature but acts on his own initiative. If he needs a more efficient and harmless antiseptic than can be found in nature he does not search the jungles or scrutinize the contents of the medicine bag of the voodoo man. He takes in hand the resorcin ring and attaches a carbon chain link by link until he finds that seven is the proper number for his purpose.

Man is entering his kingdom, the Synthetic Kingdom. At least he has caught a glimpse of the promised land from a Pisgah height and sees that the rich realm which lies before him is open to his conquest.

Primitive man was the slave of Nature. He shivered in the winter wind until he learned that by burning trees he could get as warm as he wanted. He earned his bread by the sweat of his brow until he learned that by burning coal he could get relief from labor.

Nature limited man to the power of his two legs and arms. When he annexed the four legs of the horse, man multiplied his power by ten. When he acquired the art of driving the iron horse that feeds on coal, he increased his energy immeasurably. Man has

magnified himself by the machine. He has grown to the stature of a giant and made himself master of Nature. From Nature man has learned to surpass Nature.

As Emerson says: "Nature is thoroughly mediate. It is made to serve. It receives the dominion of man as meekly as the ass on which the Savior rode. It offers all its kingdoms to man as the raw material which he may mold into what is useful."

The possibility of the extension of the power of man to turn Nature to his own purposes was first clearly perceived by Francis Bacon. He discusses Nature in three states:

First, Nature free, unobstructed or wrought upon, as in the heavens, plants, animals.

Second, Nature perverted, when she is forced and driven quite out of her course, as in monsters.

Third, Nature constrained, molded, translated and made new by art and the hand of man, as in things artificial.

Therefore, says Bacon, "Natural history treats of the *liberty* of nature, or of her *errors* or of her *bonds*."

The age foreseen by Bacon three hundred years ago when Nature becomes the bond-slave of man has come to pass in our time, or rather we are entering upon this era, through the employment of the method that he prescribed, the method of trial and error, and of scientific research for the promotion of invention. You will notice that Bacon does not fall into the error now so common among our esthetes and intelligentsia of calling Nature "perverted" when she is "molded, translated and made new by art and the hand of man." He explicitly condemns those who fall in the subtle error "of looking upon art merely as a kind of supplement to Nature, which has power to finish what Nature has begun or correct her when going aside, but no power to make radical changes, and shake her in her foundations; an opinion that has brought a great deal of despair into human concerns. Whereas, men ought on the contrary to have a settled conviction, that things artificial differ from things natural, not in form and essence, but only in the efficient." And again he says: "All I mean is, that Nature, like Proteus, is forced by art to do that which without art would not be done; call it what you will,—force and bonds, or help and perfection." For, as he says, "in things artificial Nature seems as it were made into a kind of second world." It is this second world, or a province of it, that I am calling the Fourth Kingdom.

The reason why I bring up this lesson taught by Bacon three centuries ago is because it has not yet been learned. Not long ago, I strayed into the lecture room of one of these new orientation classes that are supposed to set the compasses by which the young generation can find its way through the modern world. The teacher asked a nice young lady student to state the aim of science. She answered: "The aim of science is the study of Nature so that man may learn to live in accordance with the course of Nature." I could not repress my indignation at hearing this false and heathenish definition pass unchallenged in a great university in this so-called twentieth century, and, although I was merely an on-looker in the class, I rose in wrath to propound a counter definition: that "The aim of science is to enable man to seize the forces of Nature so that he may frustrate the course of Nature." I could have improved on that definition by more consideration, but I think it hit the mark nearer than hers. There the ungrateful girl sat in a steel and concrete building, artificially heated and lighted by electricity, reading from leaves that indeed came from trees but were not green, dressed in synthetic silk, owing even her complexion to the chemist, and she left in an automobile instead of on her own legs. She probably never used her own legs except for dancing and then to very unnatural music. She is likely to live ten years longer than she naturally would—thanks to the frustration of the course of nature by the science that she slaps in the face.

The new kingdom of which the chemist is king and founder already overlaps and may ultimately embrace the three traditional kingdoms of Nature. In the present transition state while the new régime is being established the attempt to classify products according to the old divisions is causing considerable confusion. Does a given sample of butter come from a cow or a coconut? Does a given sample of sugar come from beet or cane? Does a given sample of alcohol come from grain or grape? Does a given sample of acetic acid come from cider or malt? Does a given sample of rubber come from forest or plantation? Does a given sample of musk come from seeds of hibiscus or glands of deer? Perhaps neither; for, perchance the butter and sugar, the alcohol and the vinegar, and the rubber and the perfume may have come from coal. Nobody knows but the chemist who made it and maybe he won't tell. Anyhow, it's nobody's business if the chemist has done his business well enough so the product is correct. After a compound has come under the domain

of the chemist, it has renounced all allegiance to the kingdom of its natural origin.

We see today the strange spectacle of competition in the production of methanol from four dissimilar sources: (1) as a by-product of the distillation of wood to produce charcoal, (2) as a by-product of the distillation of coal to produce coke, (3) as a by-product of the fermentation of corn to produce butanol; and (4) as a by-product in the production of gasoline from coal, and a dozen other sources might be drawn upon whenever desired.

The world is a museum of living antiquities. We can study archeology without opening a book. Representatives of all the culture periods of the past may be found among our contemporaries. If anybody thinks he would like to live in Neolithic times he can still find a society of that sort in certain back-water parts of the earth—say, in Borneo or Africa. If he wants to try living in the pre-steam period when human muscle is the sole source of energy, he can get a close approximation to such conditions in China and India. The difference between that world and ours is well brought out by Dr. T. T. Read of the American Institute of Mining Engineers, who has lived in China. He points out in "The American Secret," *Atlantic Monthly*, March, 1927, that while China has nearly four times as many people as the United States, the amount of work done in the United States is, because of the employment of coal, oil and water power, equivalent to ten times as much as could be done by the people of China. As we might say, the eating population of the United States is one-fourth that of China while the working population is ten times as great, therefore the American is forty times better off than the Chinaman. Or, as he puts it: "Every person in the United States has thirty-five invisible slaves working for him, and the most significant thing is that these thirty-five slaves do not consume anything, so that all the product is available for the 'boss.' The American workman is not a 'wage slave,' but the boss of a considerable force, whether he realizes it or not."

The wealth of the various countries of the world is closely proportional to their employment of inanimate power. The same rule may be applied to explain the comparative prosperity of different industries. The reason why farming in this country is relatively unprofitable is because it has not yet commonly had the advantages of power and efficient management that have brought such unprecedented prosperity to city industries. The farmer as a rule does not

make use of coal in either of its two capacities; as a source of power, or as a source of material. Crops will not grow on coal nor is the steam engine applicable to agriculture. Consequently, the farmer has been left behind in the recent advances in the two fields which physics and chemistry have opened up—power utilization and synthetic production.

The power problem is on the way to being solved, for it is already apparent that it will be possible to get power in some way to almost every farm and if it is employed with as much efficiency in management as in the factory, it will have the same effect; that is, it will make it possible to raise larger crops on less land at lower cost with fewer farmers. This revolution in agriculture is even now beginning, and is the cause of considerable distress in the rural districts and a great commotion in the political arena.

The other question—How far agriculture will be invaded by chemistry—is more dubious. I have never been one of those chemists, like Berthelot, who foresee a time when all our food will be synthetic. I do not anticipate the day when we shall do away with our three meals and simply swallow a pill containing the essential elements and energy. Such a condensed diet would, it seems to me, be a hard pill to swallow, for it would have to have a density surpassing platinum, even approaching the specific gravity of the faint companion of Sirius.

I believe that the bulk of our food will continue to be raised by the aid of vegetation and that while it may be possible to make any kind of food from coal, air and water with certain salts, I doubt if it will be generally profitable to do so. So I anticipate that the future rivalry between the chemist and the farmer will turn out a drawn game, and result finally in some system of mutual coöperation, a sort of symbiosis to the profit of both parties.

I am tempted to speculate a bit at this point as to where the line may eventually be drawn between the chemist and the farmer. Dr. Baker, when he invited me to speak, did not expect me to make any serious contribution to the practical and technical problems which engage the attention of this congress, for he had me on this platform two years ago. I will not disappoint his expectation in this respect, however I may in others. In speaking before an audience of experts such as this, I should make myself liable to competent contradiction if I said anything on the subjects that you know so much about and I so little. So I shall seek to avoid this by

talking on topics that neither of us know anything about with certainty. Such safe topics I can find only in the future; especially the future of farming.

I venture as my first forecast that the farmer of the future will stop to a large extent the raising of field crops. He will raise raw materials. He will aim to produce carbohydrates, fatty acids, amino-acids and heterocyclic compounds, rather than raise sugar beets, cotton seed, beef and tobacco. He will employ whatever plants will give, in his locality, the largest yield at the lowest cost of the particular class of chemical compounds that are most in demand at the time. If, for instance, he is after alpha-cellulose for literature or lingerie, he may grow weeds. If he finds the market good for polymerized methylbutadiene, still sometimes called by the heathenish name of caoutchouc, he may take to raising milkweed, as Edison is now doing in Florida.

The farmer of the future will not confine himself so largely as in the past to the production of foods. For there is a limit to this market. We ought not to eat any more than we do and we ought not to waste as much as we do. Even if the highways are lined with illuminated billboards beseeching or commanding us to "Eat more wheat," "Eat more raisins," "Eat more apples," "Eat more potatoes," and "Eat more peanuts," we cannot follow all this gratuitous advice. My grandfather used to say to me when I overloaded my plate with some food I liked: "My boy, your eye is bigger than your stomach." But that is only true of eating. Our stomach for automobiles, radios, silk stockings and newspapers seems insatiable. Therefore, the farmer longs to get out of food production and into a field where the opportunity for high-powered salesmanship is unlimited.

Further, I venture to say that the farmer of the future will find it worth while to make the lower forms of life work for him. He has hitherto regarded molds and maggots, bacteria and fungi, in the light of enemies to be eradicated. He may turn them into his slaves, as in the early days of husbandry the wolf was converted into the shepherd dog. Such minute creatures grow faster, live cheaper, require less room and reproduce more rapidly than the higher plants and animals. Microbes that double in size and number every twenty minutes beat Belgian hares in the art of multiplication. Starting with sawdust or waste molasses and ammonia made from the air, it is possible to make all manner of fats and proteins and flavors by the aid of microörganisms. Already this field is being

entered. I have taken at my table a broth from yeast that could not be told from the best beef tea. Can the cattle business compete with the yeast plant? I visited recently a mold factory run by the United States Department of Agriculture where glucose was being converted quantitatively and in quantity into citric acid or into gluconic acid. Hitherto gluconic acid has been sold at about $100.00 a pound, or rather priced at that for the demand was limited. By this new process it may be made for 35 cents a pound. All that is needed to make the process profitable is to find a market for gluconic acid by the ton, when it could not be sold by the gram. At any rate, it is obvious that here on the borderland of biology and chemistry a series of new industries will eventually be developed, though whether the profits will go to the bacteriologist, the chemist or the agriculturist depends upon which is the most alert to seize the opening opportunity.

The unique usefulness of carbon is ascribed by modern theory of the atom to its unique arrangement of electronic orbits. The carbon atom is distinguished for its ability to get along with other atoms. It possesses to a preëminent degree a capacity for team play. It not only unites in some form with almost all the other elements except such incorrigible individualists as the helium group, but it has the capacity to combine with other atoms of carbon in the formation of chains and rings. Its tendency to promote trust formation by the merger of molecules explains why the industries dealing with carbon have a tendency to turn into trusts, chains, rings and combines of all sorts.

The building up of the Synthetic Kingdom starts with the simple atom of carbon, which is by itself the most precious of substances, as the diamond, and the most valuable of substances, as coal. The simplest compound of carbon with oxygen is carbon monoxide; the simplest compound of carbon with hydrogen is methane; the simplest compound of carbon with nitrogen is cyanogen; the simplest compound of carbon with nitrogen and hydrogen is hydrocyanic acid; the simplest compound of the four elements is urea. All these are important commodities and from these may be made all the innumberable compounds of animal and vegetable life and of the annex to nature, Beilstein's dictionary.

This is the Age of Coal. We differ on our guesses of how long it will last but we all know that it cannot last forever, and we none of us know what will follow it as the motive power of the future. Messrs.

Claude and Bougerot have proved that it is possible to get power by mixing the warm water from the surface of tropical seas with the cold water from the depths. Sir Charles Parsons suggests that we bore a dozen miles into the interior of the earth. Various inventors are struggling with the problem of converting solar radiation directly into electrical currents, thus short-circuiting the photosynthetic process and cutting out these two inefficient transformers, the plant and the steam engine. Some scientists are speculating on the possibility of extracting energy from the interior of the atom, even hoping to induce the electron and proton to enter a suicide pact and die in each other's arms, thereby converting their material bodies into immaterial radiation, regardless of the danger of blowing up the universe if the experiment succeeds in evolving more energy from the atom than is essential for its disintegration.

Old King Coal is a merry old soul and, during his reign of 250 years, the countries that have come under his sway have enjoyed unprecedented prosperity, increased in population and carried the pursuit of pleasure to a higher point than ever before in the history of the world. "Long live the King!" is the cry of all of us who are living in this Golden Age of fossil fuel, but the more thoughtful of us, remembering that such loyal prayers have never yet been answered and no reign lasts forever, have begun to calculate the probable duration of the present prosperous regime and to speculate on the character of the heir apparent.

Here in Pennsylvania most careful calculations of this question have been made by Messrs. Ashley, Reese and Sisler of your Geological Survey and they reach the startling conclusion that the reign of Old King Coal is about half over so far as this commonwealth is concerned. According to their original figures the endowment of bituminous coal was some seventy-six billion tons. Of this 5,800,000,000 has been mined and lost, and of the remainder about forty-four billion tons are recoverable. Dividing this by the average annual production gives 260 years. Taking all known factors into consideration, the conclusion is reached that in any case it would seem that 250 years will mark the end of large production from the coalfields of Pennsylvania.

If then we look forward 250 years into the future, we may anticipate the closing down of the coal business in Pennsylvania, and, by a curious coincidence, if we look back the same period in the past, we come close to the date of the birth of Pennsylvania. For in 1678

William Penn wrote his epoch-making "Epistle to the Children of Light in this Generation," in which he urged that toleration in religion be extended even to Quakers and Catholics. The Children of Light in that generation colonized the province of Penn's woods, but so energetic and generous have been their children of the present generation in digging out and distributing the means of making artificial light to the country at large, that their own store is running short.

To one who deals in realities rather than in names, the Great Powers are not named England, France, Germany, Japan or Italy, but rather Wheat, Cotton, Coal, Oil, Rubber and the like. And from the standpoint of present day political and industrial importance the greatest of these is Coal.

Civilization must have a material basis. On a very narrow basis a high civilization can indeed be erected, but it must be a civilization narrow as well as high, a sort of sociological skyscraper. Rocky Attica with a little trade in wine and olive oil, pastoral Palestine with her "golden fleece," can still teach us lessons in the beauty of holiness and the holiness of beauty. But for a civilization which aspires to dominate a continent and bring culture to millions instead of thousands of human beings Nature must be laid heavily under contribution.

Until the eighteenth century most civilizations had for their basis Food Power, whether Wheat in the West or Rice in the East. The West Indies flourished as the world's sugar bowl; the East Indies as the world's pepper pot. But today in equal rank with Food Power stands its rival Fuel Power, for we have sought out many inventions and demand more in life than the full dinner pail. As coal is still, whatever the future may say, the most convenient industrial fuel, those political units call themselves Great Powers which have King Coal to watch over their welfare.

Modern history can be told in many ways, and all of them true, though only when combined are they the whole truth. We can write in terms of sea power with Mahan, in terms of climate with Huntington, in terms of race with Lothrop Stoddard, in terms of class with Karl Marx. But surely one of the most significant ways of writing it is to write it down with carbon pencil in some such terms as this:

Historians generally concede that the human race has more greatly changed its habits of daily life, thought and action in the last two hundred years than in any previous two thousand. This new

Carboniferous Era has been based on natural energies, most of them found in fossil fuel.

At the opening of the eighteenth century Europe was a sleepy Asian peninsula with probably hardly a quarter of its present population, and the great majority of these peasant serfs. Its manufactures were literally made by hand. Its traffic was drawn by hay power embodied in horses or wind power caught in sails. Asia and Africa were for the most part unconquered; in great part unexplored. Colonial flags floated over America, but there was the merest fringe of settlement. France was the great Power of the day, largely because of her grainfields.

In a draughty little island, no bigger than modern New York State and less than half as populous, where wood had begun to be a little scant in places a little coal was being mined. For a long time its only use was as domestic fuel—and as guests at English houses may still know—it was handled rather penuriously even for that purpose. Still there was the beginning of a coal market. The mines, being lowland, were often flooded. Clumsy steam pumps were invented to clear out the water. A Scottish engineer James Watt later in the century improved this steam pump so that it would work continuously. Soon it was applied to ingenious new machines in the textile trade. The new steam engines themselves demanded more coal. This was found in abundance. Britain grew wealthy and populous. Thanks largely to her growing trade she defeated Napoleon, King Coal's first great political victory. These same wars hampered the beginnings of industry on the Continent and Britain became simultaneously the greatest coal producer, the greatest manufacturer, the greatest trader, the greatest colonist.

Within the British Isles as well, King Coal busied himself in politics. He rearranged the people, so that most of them lived in the hitherto barren North instead of the fertile agricultural South. Radicals demanded that political power be shifted to follow the movement of population, which itself had followed the coal mines. The result was the Reform Bill of 1832, and the rule of the middle classes, whose wealth was built on industry and ultimately on coal. Scotland, which had coal, became wealthy and powerful; Ireland, which lacked it, remained poor and discontented.

The nineteenth century passed. Britain ceased to dominate the commercial world. Two other countries had found a treasury of coal in their subsoil: Germany and the United States. Henceforth

there were three great industrial nations instead of one. Germany, having more coal than France, developed more industry, had therefore room for more people, and outstripped her former foe in manpower by over fifty per cent. As in Britain, the new centers of German population coincided almost exactly with the coal-bearing areas.

Germany's new coal-gotten wealth endangered the balance of power; her foes leagued themselves; she struck out with her war machine of which the blade may have been an army, but the helve was industrial power. She occupied the coal mining districts of France, Belgium and Luxemburg and with them added to her own, held out for four years against a world in arms; being finally brought down by the reserve strength of coal-mining Britain and the fresh supplies of men and arms from coal-mining America. The countries which had little coal, Austria, Russia, Italy, and the Balkan States, played an increasingly minor rôle in the war.

The problems of the peace which followed related largely to the ownership of coal in Lorraine, the Saar, the Ruhr, Upper Silesia, Teschen and Shantung. The chief internal problems of the nations were the unemployment in the coal mines, the payment of war indemnities in coal, the falling off of the British coal trade, and the radical agitations of the coal miners, always the "shock troops" of revolutionary trades unionism.

That is, of course, not the whole story, but is there any more important chapter?

According to the ancients, the world was made up of four elements—meaning by that, primary materials. These were earth, air, water and fire. That was a good guess for a first attempt at a classification of the constituents of the universe. It may be serviceable still, if we substitute for fire, the material that we moderns mostly rely upon for thermal energy; that is, carbon.

Let us say then that the primary materials with which we have to deal are: earth, air, water and carbon. The products of the vegetable and animal kingdoms are made almost altogether from air and water. From the earth comes less than one per cent, divided among a dozen of chemical elements. The synthetic chemist can make any of the thousands of substances occurring in the three kingdoms of nature whenever he knows enough and he knows enough now to make many more than occur in nature. He has access to the same sources of raw material as the plants have—air, water and earth—

and therefore can make anything that they can, and he has the advantage of being able to get his carbon in more concentrated form. We get our carbon indirectly from the air and to the air we return it directly in the original form, having used it as a carrier of the energy by which we live. But it is too toilsome and tedious a process to gather the carbon from the atmosphere so we are dependent upon the patience of plant protoplasm.

The particles of carbon dioxide have to be picked out one by one as the air passes in a tiny stream through the pores of the leaf, and the sensitive greenclad sentinels of chlorophyl watching at the gate can catch only three molecules out of ten thousand that defile by them. If none of the carbon dioxide particles elude their vigilance, the yield, after sorting over a ton of air, is only eleven ounces and out of this only three ounces of carbon can be extracted.

What would the steel manufacturer think of his job if the best ore he could get gave him only three ounces of iron per ton? And how much would he then charge for steel? But the farmer is at a still greater disadvantage than appears from this. For iron is easily separated from the oxygen with which it is attached in the ore by simply smelting in a blast furnace, but the carbon dioxide molecule is a hard nut to crack.

That is why we rely upon the accumulated carbon of the coal beds when we want this element in quantity, either as fuel for the production of power or as material for the production of synthetic compounds. So the chemist has at his command two sources of carbon, coal and wood: products of the past and present. Which he employs depends upon the current price and his purpose. Coal he can get in the anthracite form as nearly pure carbon, or in bituminous form containing other valuable constituents. Wood is essentially cellulose wherein the carbon is combined with hydrogen and oxygen in the same proportions as in water. In the same class with wood we must reckon the cellulose and similar substances obtained from the fibers of plants like cotton, since this is interchangeable and competitive with the cellulose from trees. I have seen paper made from cornstalks, cottonseeds and straw as good as any made from spruce trees. And unless we change our present practice of cutting down trees faster than they can grow, we will come to depend more and more upon annual, or at any rate quick-growing vegetation for our cellulose supply for printing and building. The next generation will doubtless be in even more of a hurry than we are and will not want to

wait twenty or fifty years for a single harvest. Already we see in our southern states plantations of sugar cane set out primarily for synthetic lumber. From the juice of the cane a by-product may be extracted if the price of sugar happens to be high enough at the time to pay to boil it down. Forestry, though one of the oldest of human occupations, still remains a semi-domesticated branch of agriculture.

To sum up then, our survey of the foundation stones of the Synthetic Kingdom we see that we have chiefly to deal with the four ele-

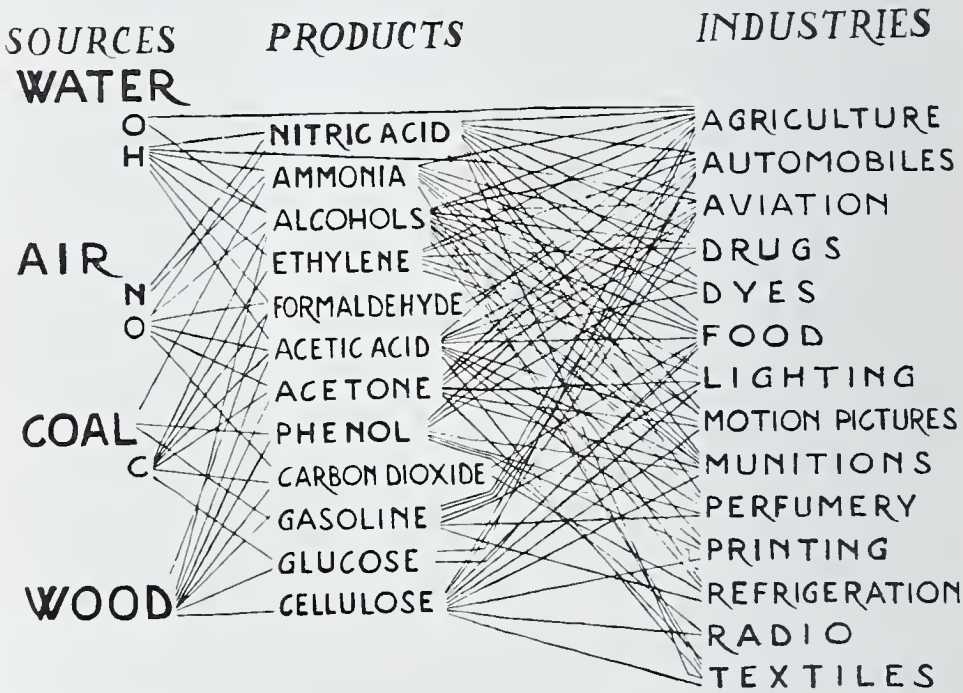

FIG. 1. CHART TO ILLUSTRATE SOME OF THE CONNECTIONS BETWEEN SOURCES, PRODUCTS, AND INDUSTRIES OF SYNTHETIC CHEMISTRY

ments, C, H, O, and N, and that we get them chiefly from four sources: air, water, coal and wood.

In order to show at a glance the interlacing of the lines of synthetic chemistry I thought I would draw off on a chart some of the simpler compounds of the four elements and connect these synthetic products with the industries which they concern. But when I tried to construct such a diagram I found it impossible. I could not get a sheet of paper big enough to allow all the lines to be drawn. For the compounds are innumerable and each of them affects in some way all

of the industries, either by contributing to its materials or by competing with its own products. But the few cases I have been able to put on the chart will serve to indicate the complicated relationships of this new industry.

I have put on the left of the chart the four primary sources of raw material for the Synthetic Kingdom:

(1) Water, from which we get the two elements oxygen and hydrogen.
(2) Air, from which we get the two elements nitrogen and oxygen.
(3) Coal, from which we get the element carbon and compounds of carbon and nitrogen with hydrogen.
(4) Wood, with which are to be classed all woody substances such as cotton and straw from which cellulose can be obtained.

From these four primary materials we could make innumerable products of which I have selected the following twelve as typical only: acetic acid, acetone, alcohols, ammonia, carbon dioxide, cellulose, ethylene, formaldehyde, gasoline, glucose, nitric acid, phenol. These enter into or concern practically all our industries, but notably and conspicuously the following: agriculture, automobiles, aviation, drugs, dyes, food, lighting, motion pictures, munitions, perfumery, printing, refrigeration, radio and textiles. These include some of the largest and most active of American industries, five of which have arisen in the present generation: automobiles, aviation, motion pictures, refrigeration and radio. These industries may be regarded as the children of synthetic chemistry. Other industries, such as munitions, textiles, dyes and drugs, have been so radically transformed through chemical synthesis as to have become in recent years practically new.

To all such industries will apply the principles which I have attempted here to outline as characteristic of the Synthetic Kingdom, viz.: varied sources, international relationships, flexibility of plant, versatility in production, utilization of by-products, correlation of processes and scientific control.

THE WORLD FUEL CONFERENCE AND THE GAS INDUSTRY: A RETROSPECT

By E. W. Smith, D.Sc., F.I.C., and T. Campbell Finlayson, M.Sc.

The World Power Conference on Fuel held in the Imperial Institute, London, from September 24 to October 6, 1928, is rapidly becoming a matter of history.

Upon certain features there will be little dispute. The large and representative membership, with delegates from 48 nations, the systematically large attendance at the various sessions, and the distinguished patronage under which the conference met, all go to show how wide an interest is taken in fuel matters. Further, the daily and technical press, realizing the predominant position of fuel in present day developments, gave considerable publicity to the deliberations of the conference.

Probably two features may be taken as being responsible for the fact that this highly technical conference occupied the attention of both layman and technician for nearly a fortnight. First, there was the international aspect. The Marquess of Reading as president stated that in his view the main impression of the conference was that representatives of many nations—some of them only recently at war—were met without regard to political differences, to engage upon a common object, with a desire not to add so much to the assets of their particular nation as to contribute to the knowledge of the whole world. That was a great ideal. That common interest of seeking to develop the prosperity of the world made them all politicians, coöperating for the great world peace for which all were striving.

World peace is a tremendous problem, but it will never come without striving and understanding. Is it a fantastic thought that—as was expressed at the time—the World Power Conference at its various meetings may act to some extent as a "catalyst" in the development of world peace? There can be no doubt that the delegates from various parts of the world did contribute papers of real intrinsic value, and thus add to the common pool of knowledge. Whether we turn to Russia, Germany, France or America, we find the publication of information hitherto unknown. Scientists and technical men discussing a specific problem, such as fuel, have no racial barriers. They find that they are faced, whether they come

from Japan or Austria, with the same need for blending coals. They find, and indeed urge that there should be world standardization on nomenclature and units, so that they may understand each other's literature. There can be little doubt that the delegates from the dominions and other lands went away from the World Fuel Conference with the feeling that they understood a little more the viewpoint and difficulties of Great Britain.

The present writer has stressed this aspect of the conference in order to show that science, at whose head is levelled the charge of being the inventor of methods for world destruction, may yet hold the most potent force for world peace.

The second feature which attracted attention was the fact that the various contributions were presented through authoritative bodies in the countries from which they originated. They therefore came with a greater force than if they had been merely individual views.

It is however, mainly on its technical merits that the Fuel Conference of 1928 must be judged. Has it made any technical contributions to world fuel problems? Have the many months of labor in its preparation merely resulted in a fortnight's meetings, and the printing of three large volumes of transactions, or will the deliberations make a vital contribution to industrial progress? This is a difficult question to answer, and one which time alone will prove, but it is the intention in the present series of articles to review the conference from the point of view of the gas industry.

At the time of the meetings many of the delegates had not had the opportunity to study the papers in detail, and this probably accounts for the fact that on the whole the discussions did not come up to the uniformly high level of the papers presented. It was indeed impossible to expect adequate discussion of a group of say eighteen papers in the course of two hours by delegates from as many as twenty nations represented at one session. A number of the papers could usefully have employed the whole of the time alloted for the consideration of a group of papers. A certain amount of criticism has been expressed concerning this "crowding" of the sessions. The organizers had a difficult problem to face. There was a limit to the reasonable duration of such a conference. It was therefore necessary either drastically to limit the number of contributions, to enable each separate paper to be presented and discussed, or alternatively to encourage the presentation of papers from the authoritative technical bodies all over the world, to group these papers under sections,

and have them discussed at the conference through the medium of a general report which discussed the main features of a group of papers, and outlined the agenda for discussion. It is felt that the high level of the papers presented is the best comment on the wisdom of the organizers' decision.

From the discussions, short as they were, it was possible to trace the trend of development in different parts of the world.

At the conclusion of a conference such as this, there are those who say "What have you told us? We knew all about these subjects before the meetings started." It is submitted that a conference may have a far wider influence than the mere revealing of new information. An idea—an improvement known to many individuals —may, by the authoritative approval and backing of a number of technical men be pushed into practical application. By the very reiteration of a proposition, it may come to sound axiomatic, and then be transferred to practice without causing any excitement.

This retrospect has a threefold object. First, to crystallize some of the information laid before the conference; secondly, to criticize and discuss certain features of the papers and discussions; and thirdly, to indicate the lessons to the British gas industry which it seems to me may be justifiably drawn.

The subjects which are at present attracting the attention of those engaged in the gas industry may, it is suggested, be summarized as follows:

1. Coördination, centralization of control, and unification and its effect on the gas industry.
2. Solid smokeless fuel production—by high or low temperature carbonization methods.
3. Developments in industrial gas sales.
4. The utilization of surplus coke oven gas.
5. Developments in methods of gas production and by-product recovery.
6. The contribution of the gas industry to smoke abatement.

What had the World Fuel Conference to say on these subjects?

Coördination, Centralization of Control, and Unification and Its Effect on the Gas Industry

If it were necessary to express the main thought which lay behind the papers and discussions in a single word it would be "rationalization." Time after time this word came to mind in a study of the

papers. It covers the subject of this section. Rationalization has recently been aptly defined as "connoting the readjustment of industrial methods and organizations to changed or changing conditions—equally whether the changes be economic or arise out of advances in scientific technique—the end in view being the elimination of waste in every form and the attainment of the highest possible efficiency."

A striking example of the need for rationalization is to be found in the present position of the British coking industry. After the War, Germany, faced with the imperative need for industrial reorganization and with a fading currency, took advantage of scientific progress, and by building large rapid coking ovens cut her costs of coke production. France, with many of her collieries in ruins, rebuilt her collieries and coke ovens on modern lines. America, with a steadily increasing demand for her iron and steel, improved her technique of oven construction with each new installation. After the War Great Britain was faced with this problem of coke production in a large number of small units, many of them worn out. With the slump which followed the post-war boom a number of ovens were let down. The coke oven owners had not, in many cases, the confidence to take this opportunity to reconstruct their plants in accordance with latest practice, and when the demand again came for coke they were faced with the operation of uneconomic ovens. But during the past three or four years there has been an improvement of the situation, and the importance of rationalization in the coking industry has been emphasized by the National Fuel and Power Committee. A well organized modern coking industry will make coöperation between gas, coking, and steel industries not only mutually advantageous but also essential for their development.

Sir David Milne Watson in his broadcast address from London on "Planning the World's Fuel," said that one thing upon which the minds of all the delegates of the conference seemed made up was that the day of the small undertaking, whether coke, gas or steel, is over, and that larger units are essential if the best results and the full advantages of our technical knowledge are to be obtained. In many industries, such as the steel and coking industries, it can readily be shown that larger units mean reduced cost. In the case of the gas industry, the evidence is not so easily obtainable. From the point of view of thermal efficiency and cost of gas production there are many small works efficiently run and containing modern car-

bonizing plants which compare favorably with much larger undertakings.

This is an important difference between gas and electricity undertakings. A small electricity generating station almost invariably means a lower thermal efficiency. Thus in the "Analyses and Summaries of the Returns of Fuel Consumption for the Generation of Electricity in Great Britain for the year ending March 31, 1928," it is shown that fuel consumption per unit generated on stations making over 200 million units per annum averages 1.81 pounds; with stations making 50 to 100 million units it averages 2.10 pounds; with stations making $\frac{1}{2}$ to 1 million units the fuel consumption rises to 7.05 pounds per unit. An examination of published returns of the gas enterprises will show that many of the small gas companies are producing as high an output of gas per ton of coal as the larger ones, and are doing so at a reasonable cost. The reason for this is that a carbonizing plant is made up of a large number of small efficient units, each complete in itself. In addition to this, sudden fluctuation in load can be taken up fron gas holders instead of direct from the carbonizing plant. In the case of the electricity generating stations, the larger units usually give lower fuel consumptions, and seeing that storage of electricity is impracticable to any considerable extent, variation of load has to be taken up by the generating set direct.

The main justification for the grouping and absorption of smaller undertakings lies in the advantages which may result from unification of control. Small undertakings cannot afford technical supervision. Even the medium sized undertakings cannot afford to finance research, nor can they afford the amount of technical supervision that is possible to the larger concerns. Again, with small undertakings the load factor is in many cases uneconomical, and they are not in the position to buy as cheaply as large ones. Nor can they afford to prepare their coal by blending, or to screen and grade their coke sufficiently.

It is submitted that rationalization of the gas industry should involve, not the centralization of gas manufacture in a few superstations, but the installation of intercommunicating mains between enterprises whose districts may be different in their requirements and their demands. This intercommunication would reduce the necessity for each enterprise having unnecessarily large amounts of standby plant, in the form of holders or carbonizing plant. Into these mains might be added, where practicable, surplus coke oven gas. For such

an arrangement to be effected, gas enterprises would have to be authorized to sell gas to each other. In addition, it would be an important step if groups of gas undertakings were themselves able to centralize and control the treatment of by-products.

An interesting suggestion towards rationalization of the by-product ammonia problem was made by P. Parrish in his paper on "Some Technical and Economic Aspects of the By-Product Ammonia Recovery Problem," H 13. He showed that, whereas the largest by-product works produces 25,000 tons of ammonium sulphate per annum, Billingham, according to the modified schemes propounded by Lord Melchett at the Adriatic Conference, will produce 360,000 tons per year. To compete with such an organization Mr. Parrish urges that the recovery of ammonia at the majority of works should only proceed to the point of making either a concentrated gas liquor containing 15 per cent NH_3, or a solution of ammonium sulphate containing 40 per cent $(NH_4)_2SO_4$. These concentrated liquids should be converted into ammonium sulphate of uniform quality at a central works.

By centralization of ammonia product works, mass production methods and coöperation between a group of gas undertakings, it is difficult to see how any synthetic process can seriously compete with by-product ammonia. A ton of by-product ammonia can be made for £3.18.0. It is highly questionable whether a ton of synthetic ammonia will ever be produced at this figure.

It may be said that the gas industry has progressed so far very well without any unification, but it cannot stand still. If rationalization is taking place in other industries, the gas industry cannot afford to stand aside. Whatever may be the view of the industry itself, there can be little doubt that the consumer thinks of the gas industry collectively. The use of gas and the products of carbonization are now so necessary to the welfare of the community that the quality of the products of one undertaking has a material influence on the attitude towards the products of another undertaking. At the present time each is a law unto itself, there being no directive control except that voluntarily adopted. If a particular undertaking realizes that new methods have to be adopted, say for the preparation of coke in order to command a higher price, and to bring it in line with a better material produced in a neighboring district, it has to bear the whole cost of such an improvement. This is sometimes impossible for a small undertaking, with the result that the small undertaking

goes on selling bad coke at a poor price, while the good coke made in the neighbouring district is, to a greater or less extent, discredited because of troubles associated with the bad coke. If the small undertaking is absorbed by the large one, there is capital available to remedy the bad coke, and thus improve the general market situation. Even if two neighboring undertakings make equally good products, there is in many cases competition to sell their by-products in the form of coke, tar, and ammonia, resulting in undercutting, whereas there should be coöperation between them, if they be regarded as units in one great industry.

Research. The World Fuel Conference brought into prominence with striking force, the importance of research work in the gas industry. Three important principles would appear to have been generally accepted.

1. The fundamental importance of technical research to the fuel industry.
2. The importance of fuller utilization of already existing knowledge available in different countries, in different industries, in different laboratories, and in recent and past literature.
3. The importance of unifying the nomenclature and standards with a view to more readily utilizing the experimental results obtained by others.

As regards research work, the gas industry in this country has passed through a somewhat unusual development. Until recent years the industry was self-contained. It trained its own men, depended upon its own resources, and had not the advantage of learning from the experience of other countries because of the fact that the subject of the carbonization of coal was further developed in Great Britain than in any other country. The processes and plant were built up largely on experience and practical experiment. But for the past two decades the industry, faced with the growing complexity and costs of modern industrial life, has realized the importance of systematic research on the technique of gas production and gas utilization. The growth of the gas industry all over the world has led to important developments being made abroad which may have application in Great Britain. This conference has shown that the gas industry can find today many points of interest and application from abroad.

Upon the present day attitude towards research in the gas industry we may perhaps be allowed to quote the words of the President of

the National Gas Council at another conference last May. "In no other industry has the advantage of chemical control been recognized more fully during the past few years than in the gas industry, and the steady increase in the efficiency of gas production has undoubtedly been due to the large increase in the number of chemists employed by gas undertakings. A natural result of this kind of control is that the industry is looking more and more to the research and investigations of chemists in order that its processes may be developed to give still more economic working in the future."

The carbonization of coal and the production and treatment of gas are complex subjects. They call for a much wider application of scientific principles than most other industries. They make a greater demand on the scientist if the same state of efficiency is to be obtained as is obtainable in other industries. Research should not be confined to the general subject of carbonization or the production of gas. Investigation is required in every branch of the industry, from coal preparation to the utilization of gas. Research is even required on the primary subject of the training of men for the industry. Still more attention must be paid to the best methods of utilizing research work. Those members of the gas industry who attended the conference will have realized that scientific research can be applied quickly and important results and improvements made if there is a real desire to do so. Too often is the research worker expected to apply the results of his work. Too often is the engineer expected to develop the details of his own process. It is the business of scientific management to coördinate the work of the research man with the practical needs of the producer. More time and money are lost annually through lack of proper management and coördination than through lack of ideas or inventive skill. The importance of coördination in connection with research work cannot be overemphasized. H. Hollings, in his highly important paper to the Institution of Gas Engineers last June elaborated the importance of careful deductions from results, over and above the mere collection of data.

There are two great fields of research work in the gas industry. There is the prosecution of research work away from the actual process of gas manufacture, with the object of developing new processes of manufacture, of gas purification, and of improving the products of the carbonization process. Then there is the field in which the research worker examines the operating results being obtained in everyday processes and from his specialized knowledge

searches for ways and means of improving the efficiency of the processes, and, in addition, puts before those controlling the works the true significance of cause and effect. The World Fuel Conference by reason of the information published gives ample opportunity for this type of research work. Rationalization of the gas industry depends to a large extent upon the vigorous prosecution of both inventive and deductive research work.

There is a further aspect of this subject of rationalization which must be considered, namely the present position of legislation governing the gas industry. As Mr. F. W. Goodenough pointed out in his paper to the conference, many of the laws controlling the gas industry date back eighty years. "If the householder and industry generally are to secure in full measure the benefits resulting from the widespread use of gas, it is essential that the industry should be freed from the cumbersome and useless shackles which restrict its full development, and that the control of this great public service should be based on modern needs and modern conditions."

For the rational development of the gas industry there are certain changes of legislation which are almost too obvious to be enumerated.

1. Gas undertakings should be allowed to coöperate with each other by buying and selling gas from and to each other, and by the joint working up of by-products.
2. Gas undertakings should be allowed complete freedom in the determination of prices of gas for domestic and industrial users, subject to the average price being the basis for the sliding scale.

It must be considered that legislation is not the only factor which limits the adoption of a different price of gas to industrial user and domestic consumer. In some of our large cities, the difficulties to be met in any proposal for altering the method of charges for gas will be in connection with the opposition of those who consider the small working-class consumer should not pay more for his gas than the large user. This is a difficulty of the same nature as to whether or not those using slot meters should pay slightly more for their gas, in spite of the fact that the introduction of slot meters, while adding to the convenience of the consumer increases the cost to the gas undertaking. The experience and results of such undertakings as Sheffield and Birmingham, with their large industrial load, should be a sufficient indication that the development of a large industrial load leads to cheaper gas for all.

One paper at the conference touched on an aspect which is little appreciated, namely the legal considerations governing long-distance transmission of gases, by H. V. Lloyd James. He indicates that before bulk transmission of gas on a national scale can be made practicable, nothing short of a complete reshaping of the law relating to gas supply must be undertaken. All the large centers—in fact the bulk of the gas supply of Great Britain—are in the hands of statutory companies and local authorities, which, in exchange for the obligations of working under certain restrictions enjoy a number of privileges, among which is a monopoly of the supply of gas within their areas.

All the protection the community requires in exchange for monopolistic conditions enjoyed by the gas undertakings can be obtained through carefully considered regulations laid down in the conditions of supply.

The gas industry is perhaps in the best position of all the established industries to make full use of this lesson of the World Fuel Conference—rationalization. It is well established, successful, a public service having legislative protection and monopolistic conditions. It has satisfactory labor conditions; on the whole it takes no great financial risks. But, for its development, it is necessary that the legislation governing it should be such that it is free to extend and evolve, to improve and change in those ways which the changing economic conditions and the changing requirements of the community necessitate. If the gas industry be allowed to "adopt, adapt, and improve" it will continue to hold the enviable position as the one great public service which never fails.

COAL CONSUMPTION AS AFFECTED BY INCREASED EFFICIENCY AND OTHER FACTORS

By Arthur D. Little and R. V. Kleinschmidt

In spite of a normal expansion in industry and in the use of power, the consumption of bituminous coal in the United States has shown practically no increase since 1918. This situation presents a problem of vital concern, not only to coal operators and dealers but to some 600,000 miners and their families who are entirely dependent on the industry for their living. Nor is the significance of this fact confined to the United States. Conditions in a country which produces half of the world's total supply of coal cannot fail to influence the industry in other countries. The same factors which are largely responsible for decreased consumption in this country are operating to some extent all over the world. We are dealing, therefore, with a problem of international significance. It is our purpose to inquire into the underlying causes of this phenomenon in order that we may gain some insight as to the extent to which this condition may continue in the future. Three factors that have checked the expansion of the bituminous coal industry are:

1. Competition of other sources of heat and power, particularly oil, natural gas, and water power.
2. Increased efficiency of utilization of coal.
3. A change in the character of our manufactured products and of our habits of life.

Oil, natural gas, and water power have unquestionably been important factors in the United States in the past few years, since they have furnished heat equivalent to 25 per cent of our coal consumption, but since 1922 there has been no definite increase in the percentage of our fuel supply furnished from sources other than coal.

The use of oil and natural gas will necessarily be short-lived so far as direct competition with bituminous coal is concerned. The runaway character of oil production in this country is already being brought under control. Once this is effectually accomplished, oil will be reserved almost exclusively for those uses for which it has a marked economic and technical advantage. It may be expected to find use in domestic heating for some time to come, and for an even longer time as fuel for internal combustion engines. In the former

field, it will be largely a competitor of anthracite rather than of bituminous coal. In the field of internal combustion engines, serious competition with coal will occur only in small industrial plants and in the propulsion of ships.

In this connection, statistics from three large electrical companies covering the decade from 1918 to 1928 show that of the electric drives installed in vessels other than warships, only 31 installations, totaling 139,000 horsepower, were for steam turbine drives as against 88 installations, totaling over 77,000 horsepower, for Diesel drives. Thus over one-third of the total horsepower of these electric drives was developed by internal combustion engines.

Natural gas is limited in its application to points a few hundred miles from its source. As the major gas fields of the United States are at a considerable distance from the main industrial centers, this fuel will be largely consumed by new industries, which may spring up in the vicinity of the gas fields or will be utilized locally as domestic fuel. In any event, both oil and natural gas as primary fuel for ordinary power and heating purposes are to be regarded as transitory. Within the next decade, they will probably be largely replaced by their equivalent, which at present amounts to 139,000,000 tons of bituminous coal.

Water power, on the other hand, will continue to be developed steadily for years to come. Our present developed water power, which represents 6 per cent of our total power requirements, is estimated to be about one-tenth of the ultimate capacity of the streams of this country. Most of this potential capacity must await the commercial development of the regions in which it is situated before it can be profitably utilized. Between 1919 and 1925 our public utility electric plants increased their water power output by only 50 per cent, while their steam power output increased 80 per cent. This 50 per cent increase is probably greater than the actual increase in total developed water power because the utilities have taken over many already developed water rights from industrial plants. We may confidently expect that the development of water power will occur so slowly that there will be no increase in the percentage of our total power developed from this source.

Although the direct competitors of coal have had their effect in the past, it is highly probable that the increased efficiency of utilization will in the future be of far greater importance. It is this factor which we wish especially to consider in detail.

The decrease in coal consumption which will result from better utilization of coal may be of very great magnitude. An increase of 50 per cent in the thermal efficiency of our processes will save 300,000,000 tons a year and such an increased efficiency is in most cases entirely possible. In table I we have shown the approximate distribution of coal consumption among our major industries.

Taking these up in turn, we find that the railroads are our largest consumers. These use 30 per cent or more of the total consumption of bituminous coal. The average efficiency of locomotives as converters of heat into power has increased from 6 per cent in 1917 to 8 per cent in 1927. A modern locomotive recently tested showed a

TABLE I

TYPICAL COAL DISTRIBUTION (1923)

	BITUMINOUS—85.7 PER CENT	ANTHRACITE—14.3 PER CENT	TOTAL
	per cent	*per cent*	*per cent*
Railroads	30.0	5.3	26.5
Industrial Uses	23.0	21.4	22.8
Domestic Trade	12.8	60.2	19.6
Electric Utilities	7.1	2.6	6.4
Gas Plants	1.0	1.3	1.0
Coke—Beehive	5.8		5.0
By-Product	10.4		8.9
Coal Mines	1.7	9.0	2.7
Other Mines and Quarries	0.8	0.2	0.7
Iron and Steel Works	5.8		5.0
Bunkers	1.6		1.4
	100.0	100.0	100.0

thermal efficiency as high as 11.5 per cent. If we assume that the average life of a locomotive is fifteen years, and that all new locomotives will be of the high efficiency design or better, we shall find it possible to move approximately 50 per cent more freight 15 years hence than we are now moving without any increase in coal consumption by the railroads. But this direct increase in efficiency is not the only way in which railroad efficiency may be expected to increase. The electrification of steam railways replaces the necessarily inefficient locomotive by a stationary power plant which, on the basis of the best present central station practice, may have an efficiency as high as 25 per cent. If we allow for a loss of one-fifth

in transmission, the net efficiency delivered to the locomotive will still be 20 per cent. This increased efficiency will be materially augmented by economies due to the better load factor of the electrified system. In an elaborate analysis made by the Geological Survey in 1921, the saving of fuel due to electrification was shown to be between 60 and 75 per cent. Recent improvements in power plant design have raised these figures. When the time comes for our railroads to be completely electrified, we shall, even without further improvements in the art of power plant design, be able to move over three times as much freight as we are now moving without increase in the consumption of coal. Although at present our total main line electrification is only about 1000 miles, three of our largest railroad systems have within the last few months announced plans for further electrification of lines in thickly settled districts, which will involve an expenditure of almost $200,000,000.

Turning next to industrial plants which use 23 per cent of our total coal consumption, an analysis in this case is more difficult since the uses to which coal is put in the industrial plant are much more varied than in the case of railroad service. A very large percentage of this coal is, however, unquestionably used under boilers to furnish steam for heating or for power generation. It is safe to assume that the average efficiency of industrial boilers does not exceed 65 per cent. Only a few years ago it was estimated at 55 per cent, but there has been noticeable improvement since then. If by the addition of air heaters, economizers, and mechanical stokers or powdered fuel burners, the average efficiency is raised to 80 per cent, we will thereby provide for a 23 per cent increase in steam consumption from our present coal supply.

Certain indirect economies will permit greatly increased industrial power and heating loads without corresponding increases in the use of coal. The generation of by-product power from steam, which is to be used for drying or water heating presents possibilities for extensive economy. This by-product power is obtained with an expenditure of less than one-third of a pound of coal per kilowatt hour. In the smaller factories inefficient boiler and engine plants are being replaced by central station power. In larger plants, waste heat is now being made to do several jobs for which additional fuel was formerly consumed. Not many years ago, cement mills burned fuel for firing their kilns, more fuel for drying the raw materials, and yet more fuel for generating the large amount of power used in grinding raw

rock and clinker. In the modern plant the waste gases from the kilns pass successively through boilers to generate steam for power and through the rock dryers. Paper mills which use large amounts of low pressure steam for drying install high pressure boilers and reduce the steam pressure by means of non-condensing turbines which generate all the power required by the mill at practically 100 per cent thermal efficiency. The magnitude of the savings of fuel that can be effected by carrying such improvements to their ultimate limit can only be conjectured, but it is not difficult to believe that our present supply of coal to industrial processes could easily be made to yield twice to three times the return that it is giving today.

In the domestic heating field, which uses 12.8 per cent of our bituminous coal supply and which is the controlling factor in the anthracite market since over 60 per cent of the anthracite sold goes to domestic consumers, the trend toward efficiency is affecting consumption in a number of ways.

In the first place, there are better designs of heating equipment available, which are slowly replacing the less efficient types of furnaces. In these latter with average efficiencies estimated at from 40 to 55 per cent, there is obvious room for improvement. The importance of perfect combustion and proper draft regulation is beginning to be appreciated. More important is the recognition of the value of insulating materials in building construction, as well as the use of metal weather strip. An air-tight house, well insulated, and with a proper ventilating system, would require surprisingly little fuel to maintain a comfortable temperature. Some attention is being paid to scientifically designed ventilation and humidification, which tends toward greater comfort and a decrease in consumption of coal. These factors, however, have up to the present been of interest chiefly in the anthracite burning districts where coal is relatively expensive.

In the meantime there has begun a movement of nation-wide significance toward the substitution of coke for both anthracite and bituminous coal, the former on a price basis, the latter in the interests of health and comfort. At present the increased use of coke as a domestic fuel is shifting the domestic market from the anthracite to the bituminous coal industry. Likewise tending to increase the use of bituminous coal is the introduction of gas for house heating, since gas is essentially a competitor of oil for this purpose. In so far as house heating by gas competes with forms of solid fuel, there is a

slight increase in over-all thermal efficiency, even when taking into account the losses during gasification.

The production of coke chiefly for metallurgical purposes uses some 16 per cent of our bituminous coal production. During the past 10 or 15 years, there has been an almost complete substitution of by-product coke for beehive oven coke and the conversion efficiency has increased from 60 per cent to about 70 per cent. A thermal efficiency of at least 80 per cent is indicated when the heat value of gas and liquid by-products is considered. As this change has been practically completed, it will not be a significant factor in the future. There is, however, every reason to expect in the near future a rapid development in the coal carbonizing industries. The coke produced will replace other forms of solid fuel, either raw bituminous or anthracite coal, and there will be obtained at the same time a very considerable tonnage of gas and of liquid by-products which will serve as the raw material for a rapidly expanding chemical industry. The extraction of the liquid and gaseous by-products results in a decrease of some 30 per cent in the heating value of the solid material. If a large percentage of the bituminous coal now used were to be replaced by coke, it might mean an increase of some 40 per cent in the coal requirements of the country. An increase of such volume is hardly to be looked for in the immediate future, since by-products in such quantity would swamp any probable market. Of our present production of tar, only 1 per cent is worked up into ultimate products, dyes, medicines and perfumes, a substantial portion is distilled to creosote oil, light oils and road tars, but the major portion is burned as fuel, so that crude tar commands only fuel oil prices. However, the intense activity in low temperature carbonization indicates the importance attached to such a development.

In the iron and steel industry, fuel economy has within recent years proceeded in several directions. In addition to the shift from beehive to by-product coke, a large percentage of which is used by the steel industry, there has been a decrease of 11 per cent in the consumption of coke per ton of pig iron. The use of oxygen enriched air in the blast furnace and in other metallurgical operations may further decrease the fuel consumption in the future. The gas from by-product coke ovens has largely replaced producer gas and oil in reheating furnaces. There has also been a significant development of internal combustion engines operating on blast furnace gas, which have replaced fuel fired boilers.

Finally, we consider the public utility electric plants, which although using only 7 per cent of our coal, have given us a most graphic illustration of the economies that can be effected by careful engineering design and development. Between 1918 and 1926, the average coal consumption of electric power plants in the United States decreased from $3\frac{1}{2}$ to 2 pounds of coal per kilowatt hour, while the best plant in the latter year was operating at slightly less than 1 pound per kilowatt hour. It is not too much to expect that within the next ten years, the average electric power plant will have reached the economy of 1 pound of coal per kilowatt hour, so that twice as much power can be generated from the amount of coal now burned. Allowing for a normal rate of increase of 10 per cent per year in the demand for electric power, this increase in average station economy will to a considerable extent make up for the increased loads, indicating only a slight increase in the actual consumption of coal.

In addition to the increased efficiency of utilization of coal in the various fields where it is now largely employed, there are a number of possible future developments which may have an effect on the consumption of bituminous coal. Although we are now reaching out into the field of conjecture, a consideration of possibilities, however remote, is stimulating to the imagination.

In connection with the gas industry, the development of gasification plants at the mines and the long distance transmission of gas has already been demonstrated in Europe and presents some interesting possibilities in this country as well. In order to obtain a gas of high heating value, which could economically be distributed over long distances, attention is directed toward the conversion of water gas to methane by a catalytic process. In this way the heat units now supplied by gas oil would be replaced by heat units obtained from coal and would thereby increase the market for bituminous coal. This process, the scientific basis for which has already been worked out, can be operated to give methane and carbon dioxide, and the latter gas can be removed and converted to the solid form for use in refrigeration. In this way a gas plant becomes a source of both heat and cold in convenient form. It has been pointed out that the use of gas to replace solid fuel will in many cases increase the efficiency of utilization so greatly as to more than make up for the losses incident to conversion.

In order to complete the picture, it is necessary to mention several supplementary factors that have been, or may be, of importance in

connection with the consumption of coal. Daylight saving, originally started as an emergency measure to conserve fuel, has been so successful that it has persisted in many of our thickly settled communities. Although the percentage of coal thus saved is not great, it may easily amount to as much as a million tons of coal a year. The general use of automobiles has diverted a considerable portion of our transportation load from electric railways and from suburban railway service. At the same time it is giving people an insight into the advantages of a wider acquaintance with the surrounding country, which will persist after it becomes imperative that fuels produced from coal replace our present petroleum fuels. In certain of our large cities, district heating from large boiler plants of high efficiency has proved successful, and it is probable that this development is saving a considerable amount of fuel. In like manner, the increasing range of economical distribution of electric power is eliminating the less efficient small industrial plant.

There is also a marked tendency in industry toward development of more highly specialized lines and more refined products. In this way it is possible for our manufactures to increase very considerably in value without increasing very materially their fuel and power requirements. Our eariler industries were largely in the heavier basic products, such as paper, textiles, iron and steel, and the mining industries, which consume relatively large amounts of heat and power in comparison with the value of the finished product. While these industries will continue to increase slowly in the future, the bulk of our industrial development will occur in the more careful fabrication of these basic products.

Prophecies as to business conditions in the future are hardly within the scope of the present paper and we have confined ourselves to the assumption that industry in general will develop in the near future at a rate comparable to that which has obtained during the past.

We have endeavored to point out that the possibilities for improved efficiency in the use of coal are by no means exhausted and that if those which remain are pursued with the same technical skill and financial courage which have been shown in the past decade, they may be expected to meet the requirements of any normal expansion of our industries without any increase in coal consumption for many years to come. When generally used in accordance with the best practice of today, with careful attention to the balance of industrial heat and power requirements and with the highest economy now

obtainable commercially, our present coal production should supply roughly twice our present heat and power demands. Still beyond are other possible economies not yet developed, but which may well claim the attention of our best engineering talent for an indefinite period.

To the bituminous coal industry with its present lack of organization this prospect of a stationary market presents a gloomy picture. The situation is one in which cut-throat competition will not only destroy profits but also throw an impossible burden on the miners, demoralize our coal consuming industries, and waste recklessly that natural resource upon which the continuance of our prosperity is basically dependent.

The crisis is one which imperatively calls for coöperation among the producers of coal themselves, and between them and the coal consumers, the miners and the public as represented by the government, all to the end that integrated production may be wisely adjusted to demand and surplus man-power turned to other industries.

The producers of bituminous coal must base their hopes of an expanding market upon efforts to develop, through research, new uses for their product. They have, as yet, little of such effort to their credit. They have left to others those investigations which, as the papers presented at this Conference and its predecessor demonstrate impressively, have raised coal to the rank of a chemical raw material with inherent possibilities of extraordinary range and promise. Already it is recognized as a potential source of oils and motor fuels, alcohols, organic acids, special solvents and a bewildering variety of useful carbon compounds. It remains with the coal producers to determine whether they shall continue to wait for others to develop and appropriate the higher values now latent in coal or whether they shall themselves realize on those values through organized research conducted in their interest and generously supported by them.

FROM COAL TO RUBBER

By Dr. Fritz Hofmann

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Coal is today the basis of a major organic chemical industry. Among the by-products which deserve mention in Pittsburgh, because of its American origin, is rubber.

Christopher Columbus, the discoverer of this rich new world, acquainted the East with this remarkable substance. However, centuries passed before the old world recognized the magnitude and significance of this western gift. Only in our day has this former museum rarity become a technical force, especially since in your country every fifth person drives an automobile with rubber tires.

The primitive forests of tropical America are the home of rubber. There in lianas, bushes and lofty trees, in euphorbiaceae, hevea and landolphia runs, through a branching milk-vessel system, that strange latex from which the Brazilian Serengeiro forms his valuable Para with its truly wonderful properties, its incomparable fiber and its astonishing elasticity. At first the wild growth satisfied the slowly growing demands of commerce. The primitive forest yielded about thirty thousand tons as its greatest yearly output. And today our industry demands six hundred and twenty-five thousand tons and the demand continually increases with the steady increase of automobiles. We owe it to the sharp insight of the Englishman, Wyckam, that the necessary material is available in sufficient amount. He opportunely caught the idea of freeing himself from the whim of the primitive forest by rational cultivation. And when this farsighted experiment proved successful from a botanical standpoint and from the standpoint of technical forestry, the new groves were able to meet the growing consumption with a sufficient annual supply of rubber. It was not America, however, which became the beneficiary of this momentous culture; in farther India, the English and the Dutch owe in large part their economic development to this clever policy of cultivation of Wyckam and his successors. On the other hand, the United States is the best customer for this article of world commerce and will probably remain so in the future. The sums which change hands on the rubber exchange were subject to violent

fluctuations and it was a simple but at the same time very painful problem in arithmetic for this country to find out what a rise in price of the indispensable rubber from 1.70 marks per kgm. to 10.50 marks meant.

In the year 1926 when you met here for the first time, there occurred the last great boom in the rubber market when prices varied between the above limits.

Almost twenty-two years ago when I was chemist in the service of the I. G. Farben Industrie, A. G. and especially of the Elberfelder Farben Fabriken, I began work on a technical synthesis of rubber. It took much daring, for experiments of this kind seem to most chemists to be entirely hopeless. However, Carl Duisberg, the superintendent of our works in Elberfeld and Leverkusen, was interested in the plan and asked for approval of the very considerable sums which I had requested; and excellent colleagues joined in my support. Was it a virgin chemical field which we were entering? No, the French, English, Russians and Germans had been tilling the thorny field of the chemistry of rubber since the latter part of the preceding century. And a citizen of the United States, Goodyear, had contributed the greatest technical advance for the practical working of rubber, with his heat vulcanizing. You see here the list of the pioneers to whom we owe the most fundamental knowledge in the field of the chemistry of rubber. If any name has been forgotten only my own ignorance and not ill will is to blame. Your fellow countryman, Pond, has long since given in excellent fashion to every scientist his due and I can refer you to his monograph.

Rubber offered at first but slight opportunity for chemical research. It was with rubber as it was with coal. Nothing remained but to treat it in the same way. It was, therefore, attacked with dry heat. It was thus decomposed; as was to be expected, gases were developed, liquids were distilled off—very low boiling, mobile oils and finally viscous oils—and there was left behind a sort of coke. This was the not very encouraging beginning. Even today all results of such treatment are not known; but the fraction of decomposed products which appeared thereby amounts to only a few per cent of the rubber experimented with. The clever insight of a Frenchman, Bouchardat, found a significance, even at a time when exact research into its chemical structure was still groping in the dark. Bouchardat suggested the idea that this colorless liquid boiling at 33°C. might be the mother substance of rubber. His intuition was later shown to

be true. It turned the interest of scientists to the substance, isoprene, and hastened the solution of its constitution. The revelation of this peculiar substance as β-methyl-1-3 Butadiene was followed by its synthesis which was accomplished by several chemists. However, isoprene had not been rendered available by this means. Even successful experimenters obtained the costly liquid only in drops, and no one could boast of more than a few cubic centimeters of it. Next, the Englishman, Tilden, succeeded in splitting turpentine oil pyrogenically in such a way that isoprene was formed. The initially small yields were gradually increased by him and by others, and Tilden himself thought at first that he had found a method of commercial rubber synthesis, since he believed that he had observed that hydrochloric acid changed isoprene into rubber. For seven years Tilden followed this idea. At length, however, he abandoned the plan. For the present consumption of the world-wide commercial product, rubber, turpentine oil would no longer be considered as a productive basis. The substance is not plentiful enough and is too dear. In this, therefore, we could not follow Tilden. We also knew that hydrochloric acid does not form rubber from isoprene. There can be no doubt that Tilden got a product from isoprene which was externally similar to rubber, and there is but one explanation of this fact. Tilden had an autopolymerizat of isoprene which—as these small samples show—can be formed in various modifications, without our being able to influence its formation appreciably, least of all with hydrochloric acid. For its formation, however, a very long period of incubation is necessary. It takes years for isoprene to solidify appreciably or to become entirely solid. But the worst of it is that such isoprene autopolymerizates are not rubber in the sense in which the rubber technologist knows it. They are simply chemical curiosities, but never a substitute for vegetable rubber.

The qualities which must be demanded of a technically usable rubber are so high that the enormous difficulty of their realization in an artificial product is sufficient to explain why we—in spite of abundant resources—have been working on this problem for twenty-two years without being able to say that we are finished or that the goal has been reached. None of you has expected that I would tell you any secrets. In the case of a technically usable rubber synthesis, it is not merely a question of general unselfish scientific knowledge. Here values are at stake which force the speaker to weigh every word which he says about these things, for such work includes a risk of

millions, and many worries for those who have taken the risk. It would be perfectly proper to take the stand that it is better to remain entirely silent in public about such delicate matters. But at such a great conference on coal this youngest child of coal, for which America has an especial interest, can in my opinion not be left out. And it will probably do no harm for the public to learn that progress in so difficult a field is made not by chance but only by sober, purposeful work lasting over a period of many years. I have already referred to the fact that we have utilized the pioneer work of numerous scientists of various countries. What we have contributed of our own was recorded before the great war in about five hundred German and numerous foreign patents. Later more has been added. Those interested can see this material. They will soon find that it deals largely with very complicated matters through which a thread of continuity is difficult to find. This was, however, not our fault, but was due to the complexity of the material. It is a well-known fact that the road to so distant a goal often follows a devious route. At the conclusion of such a journey we may see no more clearly than at its beginning. Here the paths are particularly confused.

I would have no right to speak to you here in Pittsburgh on this theme if we had not chosen coal as the most important starting point for our synthetic plans. In the case of coal, the giant of raw materials, there is no such danger, as in the case of turpentine oil, that the price will fluctuate or that a shortage will occur if ten thousand tons or even hundreds of thousands are used for such manufacture. Such trifles would cause no rise in coal prices on any exchange. That our path from coal to rubber must lead over routes which have long since been easy for every chemist is clear. Let us take acetone such as we used as a starting point with the twenty-five hundred tons of methyl-rubber which we produced during the war. We made it in an improvised plant started in 1916 and completed in 1917. The source for this acetone could then no longer be the Canadian gray lime formerly used, so we had to fall back on native coal. I need only indicate for you, of course, our stages: coal, coke, calcium carbide, acetylene, acetaldehyde, acetic acid, acetone. A long road, to be sure, but necessity compelled us to follow it. And in order to carry out the synthesis of isoprene-rubber we followed a similar path: acetylene was linked to acetone. At first it was only methods of formation which my fellow workers and I worked out, using as agents caustic potash or metallic magnesium; when, however,

our colleague, George Merling, recommended sodium amide as carrier of the reaction a better and easier way to obtain isoprene resulted. The phases through which this process goes are: acetone and acetylene are united to form 1.3 methyl butinol. If this is carefully and partially hydrated, methyl butenol results; if water is removed from this, isoprene is left. Coal is, therefore, the fundamental substance. And this holds good also of the process which is perhaps historically the most interesting and which first brought us to synthetic rubber. In it a well-known by-product of the coke ovens, parakresol, was our starting point. After long years of work, beginning in the spring of 1907, my coworker, Carl Coutelle, and I developed a technically practical way for hydrogenating this phenol according to the process of the Frenchman, Sabatier. The β-methyl-cyclohexanol thus prepared in considerable quantities we subjected to oxidation with concentrated nitric acid, thus obtaining β-methyl-adipinic acid. This was treated with hypochlorous acid and in this way changed into the formerly hardly attainable β-methyltetramethylendiamin. When we heated this strong base with methyl chloride under pressure we get from it the completely methylated quaternary ammonium salt. This product finally decomposed under distillation with caustic potash into trimethylamine and isoprene. And when we carried out the same series of reactions with phenol, the resultant was the gas 1–3 butadiene. Much work has been devoted to attempts to shorten this process which at first was far too long. These efforts, as our patents show, have been successful. This, however does not change the fact that coal was always the real starting point and will probably remain so on account of the great advantages which this easily obtainable and cheap material offers.

In August 1909 we succeeded in the Elberfeld dye works in transforming isoprene into rubber; in September in changing butadiene into its lower homolog, likewise a substance similar to rubber, and in changing β-γ-dimethylbutadiene into the new heat-methyl rubber by heating this very volatile hydrocarbon under pressure with or without addition of contact bodies. A process cannot be simpler than this. Carl Harries has called it "the egg of Columbus." We found out, however, that the process was not an unmixed blessing. The task of preparing rubber from coal through the mastery of chemical difficulties and the agglomeration of the isoprene molecules, unfortunately, did not have a happy outcome. For one who has

gone this far trouble has just begun. The rubber cost 30 marks per kilogram and on the other hand had dropped in price to 1.40 marks. Can you imagine a worse investment than this indispensable commodity? On what price can the maker of synthetic rubber count? If the natural product can be handled considerably cheaper how do his calculations stand? Much more difficult than meeting the price is the matter of equalling or surpassing the qualities of vegetable rubber in an artificial material. The demands here are almost impossible, even though it were sufficient to change the light and volatile hydrocarbon into a solid colloid in a technically practical way. However, it is not the polymerizate as such which is desired, otherwise we would have attained our end long ago with our methyl rubber produced by heat polymerization; for externally and in its behavior on the rolls it is almost an ideal product. But the preponderant mass of rubber must be subjected to mixture with other substances and especially must be subjected to vulcanizing, and everything really depends on the qualities of the vulcanized product. It is a long way from coal to this touchstone of the quality of the finished product, to the sober values which the testing machine gives. It is necessary to possess an almost fabulous optimism not to fall prey, before reaching the goal, to the feeling of resignation to which the excellent Tilden succumbed.

One who has stuck to this task, however, for twenty-two years is likely to hope for final success. In the field of technology to which this conference is devoted scientists and practical men are accustomed to the overcoming of tremendous difficulties. They know that the mountain peaks are not reached by leaps and bounds but by quiet, steady progress. Music is not necessary, nor is the fanfare of a press which is too early aroused; and he who arouses it prematurely without really having reached the goal will only make himself ridiculous. The maker of synthetic rubber would not be worthy to work at his important task if he did not learn from his material that inflexible tenacity which will finally carry him—as I at least hope—to success.

OXIDATION OF HYDROCARBONS

By Paul Dumanois

Chief Engineer, French Air Service; Technical Director, French Bureau of Liquid Fuel

The final goal of liquid fuel research is the utilization of this fuel in motors.

The use of this liquid fuel depends on the way in which it behaves with regard to the explosion on the one hand, and with regard to auto-ignition by hot points, on the other hand.

Now to conduct a conclusive experiment by using the liquid fuel in a motor, it is necessary to have large quantities of it available. It would be particularly interesting to discover a method that gave some information from this point of view, by way of an experiment with small quantities of the liquid fuel, such as can be obtained in laboratory work.

The work which we have undertaken on the phenomena of combustion in motors have convinced us that the explosion and auto-ignition by hot points, while being two distinct phenomena, are both a function of the self-ignition temperature of the mixture or of the liquid fuel.

The study of this peculiarity is accordingly of great interest.

I

In comparing auto-ignition temperatures for mixtures of air and gasoline, as they have been recorded by various experimenters, we observe a great discrepancy. In tests which we ourselves have been making for several years, we found that the auto-ignition temperature of such mixtures could vary within wide limits. In certain cases it had been possible to have auto-ignition at a low temperature between 200° and 300°C., while in others it was possible to reach temperatures above 400° without ignition. Such discrepancies could be observed in running motors.

We have thus been led to systematically study the auto-oxidation of hydrocarbides in the presence of air, under pressure, and at various temperatures.

Our first experiments, which will be treated in this paper, were made with pentane and benzene. The temperature during experi-

ments varied from 0° to 300°C.; this upper limit was certainly higher than the temperatures at which anomalies had been met.

The experiments were made at the Superior Chemistry School of Mulhouse by one of our best assistants, Dr. Mondain Monval, lecturer at this school.

The pentane used had the following characteristics:

Boiling point (p = 739 mm. of mercury)	33.5°C.
Density at 0°C. (water at 4°C.)	0.645
Refraction index at 20°	1.3565
Traces of unsaturated carbons.	

The apparatus used was a steel bomb of 700 cc. capacity. The wall thickness was sufficient to withstand a maximum internal pressure of 300 kg. per square centimeter (4,400 pounds per square inch). The bomb was contained in a closed stove heated within definite limits by gas burners and could revolve by means of a small hot air motor, so as to secure an equal distribution of temperature, which was made easier by a slow heating. The time required to bring the temperature from room temperature (20°C.) to 250°C. was about 45 minutes. The temperature was measured by a mercury thermometer in a thin walled cylinder extending within the bomb. The pressure was read on a manometer.

All experiments were conducted with the same initial data, so as to obtain comparable results:

Room temperature	20°C.
Initial pressure	5.300 kg. above atmospheric pressure

With such conditions, the volume of pentane corresponding to complete combustion is 0.5 cc.

The only variable quantity being the proportion of pentane, curves have been plotted showing the correspondence between pressure and temperature.

The following results have been observed: (See Fig. 1).

1. If the volume of pentane is between 0.4 and 0.5 cc. it is less than the theoretical volume of complete combustion. Ignition does not occur below about 300°C. The curve begins by a linear part with a great slope until temperature of 40° is reached. This corresponds to a progressive vaporization of pentane. Afterwards the curve is sensibly linear. At about 250°, we have a sudden increase of pressure and then a new linear curve, nearly parallel to the pre-

ceding one—no ignition until 300°. J. S. Lewis had observed similar facts when heating at atmospheric pressure a mixture of pentane and air corresponding to the theoretical combustion. (*Jour. Chem. Soc.*, 1927, cxxxi, p. 1555.)

2. For a volume of pentane equal to the theoretical volume for complete combustion 0.5 cc. we observe, after the pentane has been vaporized, a straight line up to 120°; its slope is somewhat below the slope of the line corresponding to a mixture of pentane and nitrogen.

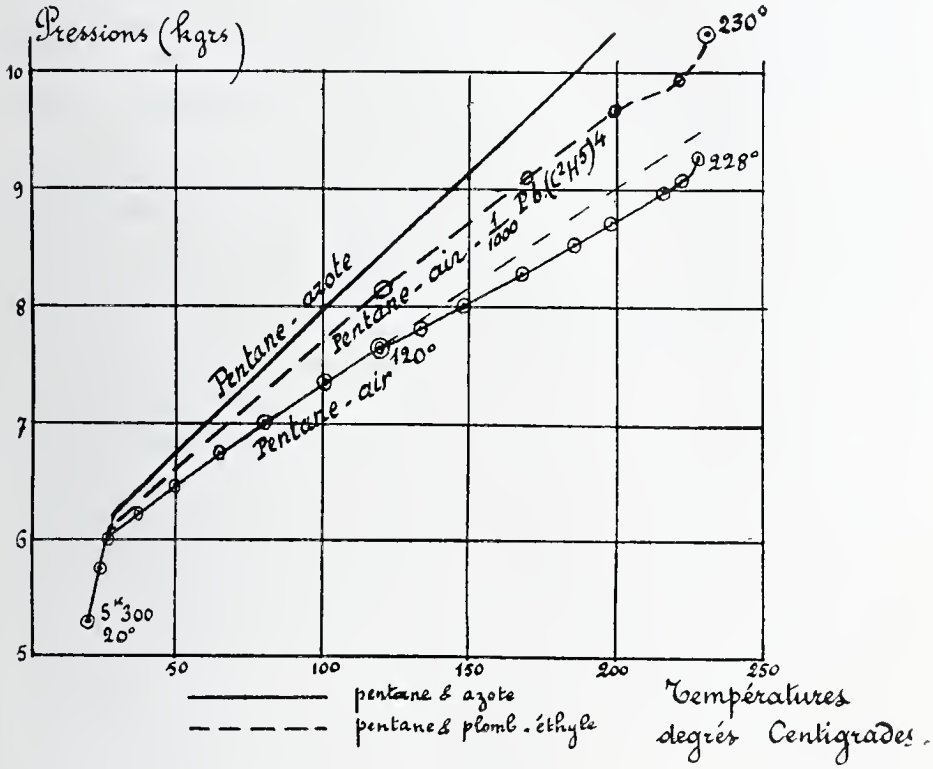

FIG. 1

From 120°, the pressure is less than that corresponding to the extension of the preceding straight line. From 220°, a sudden increase of pressure may be noticed. Auto-ignition occurs at 230°, with the appearance of a violent explosion: the needle of the manometer is launched and goes farther than 70 kg. By cooling steam is condensed and the resulting liquid possesses a slight acid reaction. No carbon black is deposited.

For a volume of pentane comprised between 0.5 and 2 cc., the curve obtained is similar with a singular point at 120°. The ignition

temperature decreases when the pentane proportion increases, and is, for instance, 228°, when the initial volume of pentane is 1 cc. The explosion is less violent; no carbon black is deposited.

3. If the volume of pentane is taken between 2.5 and 4 cc., curve is still similar with the singular point at 120°; auto-ignition occurs from 226° to 220° and is preceded by a pressure increase. The phenomenon is more like a combustion than an explosion. A carbon black deposit is found, which is maximum for a volume of pentane of about 3 cc.

The curve plotted for 3 cc. may be taken as typical for all cases where ignition occurs; we must observe that the ignition temperature decreases when the volume of pentane increases, and that ignition follows a sudden increase of pressure.

4. For volume of pentane between 4, 5 and 10 cc. a singular point is always met at 120°. Ignition takes place at about 220°; combustion is slow. No smoke black is deposited.

We find then, that the proportion of pentane has a considerable influence upon the ignition temperature and the process of combustion as the carbon black deposit may be found only within certain limits.

The ignition pressures shown by the needle of the manometer must not be considered as an absolute value, owing to the inertia of the needle, but only as giving an idea of the violence of combustion.

If we plot the curve of maximum pressures corresponding to the various proportions of pentane, we observe that the maximum of this curve is obtained for the lowest proportion of pentane giving auto-ignition, which means a proportion slightly inferior to the theoretical proportion corresponding to complete combustion. Afterwards the value of the maximum decreases when the proportion of pentane increases. A minimum is reached corresponding to 3 cc. of pentane (for which the black smoke deposit is maximum); then the maximum pressure increases and falls suddenly to a very low value for about 4 cc. of pentane, when the black smoke deposit ceases. Afterwards the pressure increases according to a linear law.

II

We renewed our experiments after adding to the pentane a slight quantity of tetraethyl lead (1 to 1,000 of pentane). This proportion corresponds to the actual practice in automobiles and permits an increase of the compression rate.

We observed the following results:

1. If the pentane volume is less than a quantity comprised between 0.5 and 0.6 cc., no ignition occurs below 300°. The pressure varies with the temperature according to a sensibly linear law, with a slight increase of pressure at about 270°.

2. For pentane volumes comprised between 0.6 and 2.5 cc., the singular point in the curve of variation is met at about 120°. The singularity is less apparent than in the first series of experiments. A slight increase of pressure precedes auto-ignition, which occurs at temperatures which decrease when the proportion of pentane increases, and which are comprised between 251° and 240°. The explosion is relatively less violent.

3. For volumes of pentane comprised between 2.5 and 5 cc., the singular point is nearly undetectable. The pressure increases just before ignition, which occurs between 236° and 228°; combustion is slack. A carbon black deposit is found.

4. From 5 to 8 cc. of pentane, there is no singular point in the curve. There is a slight increase of pressure before auto-ignition at about 228°. No carbon black deposit, and the combustion is a very slow one.

If we compare the preceding results with those obtained without tetraethyl lead, we conclude that tetraethyl lead necessitates an increase of pentane above the theoretical quantity corresponding to complete combustion in order to obtain auto-ignition. A fall of pressure below the value corresponding to a linear law is detected but slightly, and cannot be compared to the fall encountered when pure pentane is used. In certain cases, it is not observed at all.

Auto-ignition temperatures are sensibly higher with tetraethyl lead than without, and are comprised between 251° and 228° instead of between 230° and 220°.

For corresponding volumes of pentane the explosions are decidedly less violent and the curve of maximum pressures plotted as aforesaid is decidedly below the curve corresponding to the first series of experiments until we met the point of discontinuity of this first series; afterwards the second curve is above the first.

To sum up, tetraethyl lead diminishes the discontinuity in the process of combustion, when carbon black deposit ceases to be found. This deposit is more agglomerated when tetraethyl lead is added than when pure pentane is used, and is found for volumes of pentane reaching 5.5 cc., when it ceases at 4.5 cc. if tetraethyl lead is not added.

A slight proportion of tetraethyl lead has then a considerable influence on the oxidation of pentane in that it chiefly increases the zone where auto-ignition does not occur below 300° beyond the quantity corresponding to complete combustion; it also increases the value of auto-ignition temperature when it occurs.

Such results have a considerable importance in motor practice. They may be explained by the theory of Messrs. Moureu, Dufraisse and Chaux on auto-oxidation and anti-oxygen substances, if we admit that at 120° noticeable quantities of unstable peroxides are formed, which are decomposed at 210°. The auto-ignition temperature observed should not relate to an air-pentane mixture, but to an air-peroxide-pentane mixture. The anti-oxygen activity of tetraethyl lead would diminish the rapidity of formation of those peroxides; and that could explain why the limit at which auto-ignition begins to occur is raised, and also why the auto-ignition temperature is higher.

III

Similar tests have been made with benzene under the same conditions. No singular point, nor auto-ignition below 300° was met. These results are in accordance with non-oxidizability of benzene. The same experiments under the same initial condition, but using mixtures of pentane and nitrogen instead of pentane and air, gave a linear law for the pressure; the slope of this line was somewhat higher than the slope of the line corresponding to the air-pentane mixture below 120°. This may be explained by the fact that oxidation begins before the singular point.

We thought it would be useful to disclose these first results obtained in our experiments, which we shall methodically continue. We believe that the experimental method adopted by us may lead to a determination of the detonating properties of hydrocarbons and of the anti-knock power of dopes. This question is of first importance in studying the possibilities of using synthetic motor fuels.

A STATEMENT BY ARMANDO ROA, DELEGATE OF THE CUBAN GOVERNMENT

On behalf of the Cuban Government I wish to express my appreciation of your invitation to this convention. Knowing that your request that Cuba be represented here today was prompted by an carnest and genuine desire to afford us the opportunity of participating in this conference, my Government gratefully and with pleasure accepted it in that spirit.

I realize fully that the primary object of this conference is the furtherance and development of the bituminous coal industry. I realize too that this conference is purely of a technical and scientific nature. However, since Cuba does not have bituminous coal mines, and only some unimportant claims have been staked in the province of Camageuy, she is represented not as a producer but as a consumer. Therefore, I have prepared a statistical table of the importation of coal into Cuba for the past twelve years, up to 1927, which shows that my country consumed during that period, 10,973,239 tons of bituminous coal, worth $64,744,344.00. This means $1.50 per capita consumption in a tropical country, where there is no need of heat except for commercial purposes. In calculating this cost per head, I took the population figures of the year 1928, so as to be more conservative in my estimate. (See Table I.) This importation of bituminous coal is largely destined to the sugar mills, although some of it is used for bunkerage. The Cuban sugar mills use cane waste or bagasse in their furnaces to turn the machinery for either grinding or refining, but must burn coal in their locomotives for conveying the cane to the mills. There are in use at the mills two kinds of boilers, one that uses fuel oil and another that uses coal. Due to the uncertainty and the fluctuations in coal prices, preference is being given to the fuel oil in some of the new installations. In places not easily accessible Diesel motors are being urged. Coal is also used in the machine shops of the Cuban railways; however, they burn fuel oil in their locomotives as it seems to be cheaper than coal. At least two-thirds of the coal enters Cuba through the port of Havana by ship and there are considerable and adequate facilities for loading and discharging there. The United States and England are the main suppliers of coal.

During the year 1926 there were in use in the public lighting system, 35,249 lights with 451,970,021 candle power. The monthly consumption of kilowatts amounted to 56,340,178; while 214,341 cubic meters of gas were consumed; the cost per unit of kilowatts is 16 cents. The whole monthly expenditure for electric energy was $102,800.84. The total expenditure during 1926 in public electric lights amounted to $1,395,762.70.

In Cuba coal is imported duty free, notwithstanding the fact there is a port toll of 10 cents per ton levied in Havana for port improvements. Coal prices range from $7.50 to $8.50 per ton. The coal is usually supplied to the sugar mills on three months' credit. Other industries are allowed only thirty days' credit. Bunker coal is generally transacted on a cash basis. Incoming ships, either from the United States or England, very rarely demand or require coal, for they usually replenish their bunkers at the port of sailing.

TABLE I

Importation of Bituminous Coal into Cuba, from 1915 to 1927

CALENDAR YEAR	TONS	VALUE
		dollars
1915	1,092,228	3,463,528
1916	1,190,025	4,170,610
1917	1,412,201	8,807,561
1918	1,397,078	10,192,075
1919	996,019	6,432,103
1920	1,006,778	9,283,185
1921	739,807	5,813,771
1922	527,590	2,867,572
1923	620,854	4,088,503
1924	461,697	2,266,407
1925	480,252	2,076,626
1926	531,388	2,583,516
1927	517,272	2,698,672
Total.....	10,973,239	$64,744,129

I should like to add that our president, General Machado, is keenly interested in everything that tends to modern progress and advancement, and is ever on the lookout for whatever brings added benefits and prosperity to the nation; so we consider it a great privilege that we should have been able to attend such an important conference.

A CHEMICAL ENGINEERING VIEW OF COAL PROCESSING

By H. C. Parmelee

Editor, Chemical and Metallurgical Engineering

Bituminous coal to the chemical engineer is not only a source of heat and energy; it is also an important raw material for industrial processes. The manufacture of coke, gas, and by-products from coal is carried out by a series of operations most of which are inherently chemical engineering in character. These operations are today applied to about one-fifth of the bituminous coal produced in the United States; and the percentage of the coal which is being processed is constantly increasing. One may, therefore, with considerable justification forecast the time at which coal as a raw material will be as important as coal used directly for heat and power.

By-product coking as practiced in America affords a fine example of the successful joint effort of the mechanical engineer and the chemical engineer in the utilization of a natural resource. Reduced to its simplest terms, the by-product plant is a series of independent operations, separately controllable, each one of which, for economic success, must be satisfactorily coördinated with all the other steps in the processing. Some of these operations are mechanical, some of chemical engineering nature, and some require both types of study.

The unit operation of major importance is, of course, that of destructive distillation of the coal in the gas retort or coke oven. This operation is essentially one of heat transfer from the fuel-gas heating flues through refractory into the coal mass. This vital stage in the processing must be carried out under accurately controlled conditions.

Following the primary stage of processing in the oven itself there is a series of mechanical-handling operations on the solid product, coke, and a series of chemical-engineering operations on the liquid and gaseous products which have been volatilized from the carbonization chambers. It is well known that the handling of the crude gas must be carried out with a proper regard for temperature and pressure in order that the separation of tar, ammonia either as liquor or as sulphate, light oil, and occasionally other products, may give the maximum yields of each with the minimum of contamination by the other products. It is not so generally recognized that the apparently

very simple operations of condensing, scrubbing, purifying, etc., are in reality somewhat complicated chemical engineering phenomena.

Problems of liquid and vapor condensation are common to many industries. The chemical engineer has, therefore, often gone far afield from the gas and coke business to discover the latest and best of engineering technology. It is constantly his effort to adapt such improved methods and equipment as are developed in any branch of industry to the needs of the coal-processing plant. This is true not alone in the operation of crude gas condensing. It is equally true in the matter of gas scrubbing for ammonia elimination, in the operation of tar-fog extraction, in the handling of sulphuric acid as an absorbent for ammonia from the gas, in oil washing for light-oil recovery, in the refining of the tars and the light oils, in the preparation and handling of ammonium sulphate, and in a multitude of other operations about the works.

Breadth of the Chemical Engineering View

There is practically no one of these steps in the process of by-product recovery or by-product refining that does not have a close analogy in a dozen other industries, even in many plants and processes which might appear to have nothing in common with the gas and coke business. Light oil refining is exactly comparable with the production of petroleum distillates and both industries find their processing counterparts in the fundamental unit operations of distillation, heat transfer, agitation, and mixing. Centrifugal separation of ammonium sulphate in the by-product plant is effected by the same equipment that the sugar refiner uses in drying his product. In short it is because of his acquaintance with such a wide variety of process industries that the chemical engineer brings to each plant a type of service that is distinct from that rendered by any other scientist or technologist. His function is to serve as a liaison agent between these various branches of industry which have only recently begun to appreciate their interdependence and their community of technologic interest.

In the field of coal processing the chemical engineer has, however, another and a peculiar and important function. He serves not only in the designing and adaptation of unit operations; it is also his duty to coördinate the succeeding operations one with the other, and to coördinate the processing schedule with the prevailing outside

market conditions. Let us first consider that coördination which goes on within the plant itself.

In the first place the selection of the coal itself sometimes offers an effective means of control, since its character determines the operating procedure to be used to give the desired range of finished products.

The chemist in the laboratory has recently made great progress in his study of coking characteristics and other properties of coal. The chemical engineer in the plant applies this new knowledge in control of production.

The crushing and screening of coal preliminary to its carbonization is essentially a mechanical engineering task. It would be quite as presumptuous for the chemical engineer to claim as his prerogative the designing of screens and crushers as it would be for him to set himself up as the dominating expert in the field of material handling. The wise chemical engineer makes no such claim. He does, however, assume it to be his responsibility to determine what is the desired size or proportion of sizes of crushed coal which should be charged into the oven. It is clearly his duty to determine whether the optimum yield of products is obtained with coal of one-half-inch maximum size or twice that diameter. Moreover, it is his duty to determine how the presence of more or less very fine coal in the charge affects the rate of coking, the strength of the coke, the yield and heating value of the gas, and other operating results. However, he recognizes that when he has ultimately determined upon the optimum proportion of sizes of any coal or coal mixture he should at that stage call on the mechanical engineer to design for him the elevating, crushing, and screening equipment which will most efficiently carry out the purely mechanical engineering function of making such size mixture with that particular coal.

Obviously, the widest latitude in choice of operating conditions is offered the chemical engineer in his determination of the conditions for oven or retort operation. Within the limits of the properties of his refractory and his coal he may choose any combination of temperature, time, and pressure conditions that seem to him most appropriate. His choice of these conditions cannot usually be determined on the basis of any single product. Rarely is there a plant which can rightly view any one of its products as of sole interest in determining the conditions of coking.

Some coke plants affiliated with iron and steel works have at times mistakenly assumed that they are interested only in the yield and the

quality of the coke. They are correct in assuming that these considerations are of primary importance, but at no time are they justified in assuming that they are of exclusive significance. It may be that the local prevailing conditions in the way of industrial gas market are such as to warrant large sacrifice in gas yield if thereby the coke may be bettered even to a small extent. Similar lack of interest often prevails with respect to either tar, light oil, or ammonia yields or markets. But it is a serious economic error to assume that because these considerations are minor they also are negligible.

Interrelationship of Technical and Economic Factors

Our chemical engineering knowledge of the phenomena which take place during the coking of coal is fairly limited. However, we do know enough empirically so that very often we can achieve in a coke plant the desired improvement in coke or gas characteristics by any one of a number of possible courses. Often one of the procedures, giving the desired result, will unavoidably be injurious in its effect on yield or quality of some other desired product. The alternative procedure may not have this disadvantage. It is the chemical engineer's function to study these interrelationships of processing conditions and products so that he may choose for the management that combination which has the maximum over-all merit.

In the making of these choices the chemical engineer begins to exercise the second part of his function. He cannot soundly advise the management as to desirable plant operating method or most advantageous raw material unless he studies these in relation to all pertinent outside market conditions. He must know the prevailing demand and market price for all of the products. He must study the probable influence of increased or decreased production on these market factors. He must determine accurately the extent to which quality of product affects obtainable price. Only when he has taken into account all of these considerations is he really in a position to choose the optimum operating practice. And furthermore, once he has set up such a condition he must be continuously alert to changing conditions in order that he may anticipate them and modify plant practice before economic diaster overtakes in one way or another.

The chemical engineer is particularly well fitted to exercise this function of economic-technologic adviser in the field of coal products, because it happens that almost every material made at the coke and

gas works goes into other chemical engineering industries. It is not unreasonable to ask the chemical engineer, therefore, to know whether ammonia liquor or ammonium sulphate should be made; or whether perchance it is the sound economic time at which to begin the production of ammonium phosphate or the marketing of ammonia from by-product sources in the anhydrous form. Properly to answer such a question he must know the trends that are dominating inorganic fertilizer nitrogen, he must know the relation of by-product ammonia to Chilean nitrate and synthetic ammonia, especially he must keep in touch with the rate at which synthetic ammonia is displacing ammonia previously made from by-product liquor.

Similarly, in the case of tar products and light oil, the chemical engineer should know at what stage the gas and coke works will find it justifiable to burn their tar and when refining is economically justified. He must be able to advise whether the crude light oil should be marketed as such, or whether motor benzol and solvents should be made.

These questions are not easy to answer at any particular time. Furthermore, when once answered correctly for today they must needs be studied again to gain the answer for the economic tomorrow. Rarely can anyone not conversant with trends in technology as well as trends in market conditions properly analyze all factors bearing on these questions. And when he is able to answer the questions logically with respect to outside industrial relations, the engineer must go back into the plant and see to it that the maximum yields of the most wanted products are made, by the most effective technology, from the most economic raw material available.

Other Chemical Engineering Aspects of Coal Processing

While the chemical engineer has been studying coal processing in those gas and coke works which use some variation of the coal-gas process, he has also been giving thoughtful study to the alternative means for making the same or equivalent products. A very large part of the advance which has been made in the manufacture of water gas from bituminous coal has been the result of such investigations by chemical engineers. These men have attacked that problem as an important physico-chemical study to be carried out on an industrial scale. They have made all of their investigations with a view to determining as accurately as possible the proper economic niche in our fuel system for the bituminous water-gas process. Any such

process is essentially competitive with all other gas-making processes. Unless it affords economic advantage under the conditions where installed it represents bad engineering.

Similarly, the chemical engineer has given thought to the problems of low-temperature and intermediate-temperature coal processing. He wishes to determine how they should parallel and to what extent they will successfully compete with the conventional high-temperature procedures. In this determination he has been sorely handicapped by the lack of adequate knowledge as to the properties and behavior of coal during heating. Indeed, it is amazing to realize that of all the important materials used by industry there is probably none regarding which we know so little as about coal.

In the judging of new and especially of radically different processes it is not unusual to find that claims are made which are unusual, or even impossible. In order to detect these economic fallacies, the chemical engineer finds it very valuable to work out a weight balance for each constituent and an energy or heat balance for the process as a whole. Not infrequently do such tests reveal the equivalent of perpetual motion in the claims of process advocates. An over-all thermal efficiency of 110 per cent naturally leads to suspicion and a weight balance showing 20 per cent more carbon in the products than in the coal processed should be equally disquieting. Similar tests based on sound physico-chemical laws can be applied to each of the several steps in the coal treatment or in product recovery. Such tests both disclose the fallacious and give warranted encouragement to the new developments of merit.

No one realizes better than the chemical engineer that we are today in an era of rapidly changing economic relations. He knows that a process which is profitable today may be profitless tomorrow unless it adapts its methods and its products to the changing market conditions. Executives are not making an unreasonable request of the chemical engineer when they demand that he shall forestall for them such financial misfortune by forewarning them of changing conditions that affect present plant operating methods or prevailing markets for present products. This responsibility can rightly extend also to the judging of new processes.

ANALYSIS OF THE CONSUMPTION OF BITUMINOUS COAL IN THE UNITED STATES[1]

By F. G. Tryon and H. O. Rogers[2]

In the marketing of most commodities more is known about supply than demand, a fact especially true of bituminous coal. The American coal producer knows how much he ships but seldom keeps a detailed record of the uses to which his coal is put; indeed, if he sells to a wholesaler or retailer he may never know the name of the ultimate consumer. It is therefore impossible to obtain accurate figures of consumption from the producers. If, on the other hand, one turns to the consumers he finds the task scarcely less difficult, for bituminous coal is purchased in the raw state by a larger number of buyers than any other material of industry. For example, there are in the United States some 90,000 concerns who purchase coal in carload lots.[3] Of these about 38,000 are retail dealers or peddlers who in turn serve not only the millions of farmers and city dwellers but also the hundreds of thousands of consumers that make up "the small steam trade." There are, for example, 290,000 manufacturing establishments in the country, the majority of which buy coal from retail dealers in less than carload lots.[4] Because of the great number of consumers, absolute accuracy cannot be attained for some of the items in the country's coal budget. Certain of the largest items, such as locomotive fuel and coal for the manufacture of coke, can be measured with a high degree of accuracy, but in order to complete the picture, it is necessary to piece together indirect information from many scattered sources, some of which are contradictory.

The first complete analysis of consumption was undertaken by C. E. Lesher and covered the year 1915.[5] More detailed and accurate

[1] Published by permission of the Director, U. S. Bureau of Mines. (Not subject to copyright.)

[2] Coal Division, Bureau of Mines.

[3] Lesher, C. E., Report of the Distribution Division of the U. S. Fuel Administration; Part I, The Distribution of Coal and Coke, 1919, p. 123.

[4] Fourteenth Census of the United States, 1920, Vol. VIII, p. 14. In addition there were 5,678 power laundries, 2,156 dyeing and cleaning establishments, 5,376 custom sawmills, 10,427 custom grist-mills, and 22,361 mines and quarries.

[5] Lesher, C. E. Coal, Part B, Distribution and Consumption. Mineral Resources of the United States, 1915, Part II, U. S. Geol. Survey, p. 433.

studies were made by Lesher, W. T. Thom, Jr., and Wayne P. Ellis for the United States Fuel Administration during the War.[1] The latter studies which covered 1917 and 1918 were the basis of the allotment and zoning regulations of the Fuel Administrator. They are noteworthy as giving accurate records of the total consumption of coal in each state and include the only measurements ever made of the consumption for domestic purposes.

The present discussion aims (1) to give a typical cross section of consumption under present conditions and (2) to trace the changes in the requirements of the principal groups of consumers over a period long enough to establish the trend and thereby provide some basis for a forecast.

Total Annual Consumption

Excluding exports and allowing for changes in stocks, the annual consumption of bituminous coal in the United States is now about 500,000,000 tons.[2] In the last decade, it has fluctuated between a minimum of 390,000,000 tons in 1921, a year of acute industrial depression, and a maximum of 533,000,000 tons in the active year 1926, when the demand was stimulated by a strike of the anthracite miners. In 1927 the consumption was 499,700,000 tons and in 1928, according to present indications, it will be slightly less.

Relation to the Total Energy Consumption

As the total consumption of energy in the United States is now equivalent to 1 billion tons of coal, it is seen that bituminous coal furnishes a little over half of the country's total requirements. The relative importance of the other sources is shown in Figure 1, which covers the year 1927. Including anthracite, coal furnished 58.4 per cent of the total. Oil and natural gas now contribute more than one-fourth of the whole. Contrary to popular impression, water power supplies only a little over 6 per cent. Five and one-half per

[1] Lesher, C. E. Coal, Part B, Mineral Resources of the United States, 1917, Part II, U. S. Geol. Survey, p. 1203; and Coal, Part B, Mineral Resources of the United States, 1918, Part II, U. S. Geol. Survey, p. 1315.

Lesher, C. E., Report of the Distribution Division of the U. S. Fuel Administration; Part I, The Distribution of Coal and Coke and Part III, Statistical Tables, 1918.

[2] Tryon, F. G., Kiessling, O. E., and Mann, L. Coal; Mineral Resources of the United States, 1926, Part II, Bureau of Mines, p. 437.

cent is derived from firewood which is still widely used in some sections of the country. Work animals, once the dominant source of motive power, now furnish only 2.5 per cent.

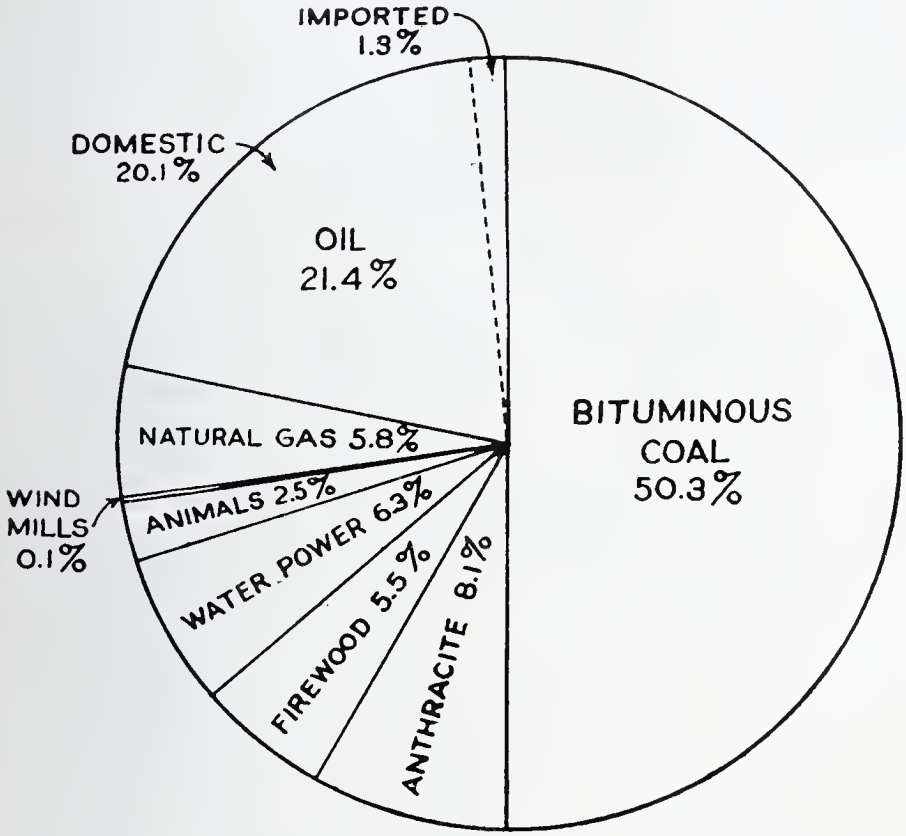

FIG. 1. SOURCES OF THE ENERGY SUPPLY OF THE UNITED STATES, 1927

The total heating value of the fuel produced or of the fuel equivalent of other sources of power was 26,950 trillion British thermal units. In this computation water power, windmills, and work animals are represented by the heat units in the fuel which would be required to do the same work.

Note that 86 per cent of the total energy is supplied by the mineral fuels, and that in spite of the rapid growth of oil and natural gas, more than half of the total is supplied by bituminous coal.

GEOGRAPHIC CONCENTRATION OF CONSUMPTION

How large a part of the total consumption is concentrated in a few relatively small areas is seldom appreciated. Seventy-three per cent of the bituminous coal is used in the industrialized section north of the Ohio and Potomac Rivers and east of the Mississippi, yet even in this region there are areas of sparse consumption, and the great

bulk of the tonnage is consumed in a small number of manufacturing centers of which Pittsburgh, Chicago, Cleveland, New York and northern New Jersey, Youngstown, Detroit, Buffalo, Johnstown, Philadelphia, Boston, Baltimore, Bethlehem, East St. Louis and Cincinnati are the most important. Some idea of the high degree of concentration of the industrial demand is conveyed by the fact that 85 of the 3,093 counties in the United States consume 51.8 per cent of the coal required by industry.[1]

Relative Demand for Prepared Sizes, Screenings, and Run of Mine

Over the country as a whole slightly more than half of the product is still shipped as run of mine. In 1927, run of mine constituted 50.2 per cent of the total bituminous shipments, prepared sizes 29.3 per cent, and screenings or slack 20.5 per cent. The relative proportions of prepared sizes and run of mine vary widely in different parts of the country, depending on the demands of the market. (See Fig. 2.) In areas where much coal is sold for household fuel the bulk of the product is screened and sized, and the proportion shipped as run of mine is correspondingly low. In Franklin County, Illinois, for example, only 9 per cent of the shipments in 1927 were run of mine, 59 per cent being prepared sizes and 32 per cent screenings or slack. On the other hand, areas where the domestic trade absorbs a small part of the production are characterized by high percentage of run of mine. In the markets accessible to central Pennsylvania anthracite is the usual domestic fuel, and the demand for bituminous for household use is small. It is, therefore, not surprising to find that over much of this district 90 per cent or more of the shipments are in the form of run of mine.

[1] That is, of the coal consumed by coke ovens, gas plants, iron and steel works, railroad shops, and general manufacturing establishments. The figures cover 1919, but are also representative of present conditions.

FIG. 2. VARIATIONS IN THE DEMAND FOR PREPARED SIZES, SCREENINGS, AND RUN OF MINE, AS SHOWN BY THE PER CENT OF RUN OF MINE IN THE SHIPMENTS FROM EACH COUNTY IN 1927

The map covers the coal-mining counties that produce as much as 100,000 tons a year. Counties in which the demand for house fuel is relatively large show a low percentage of run of mine and appear on the map as white or very lightly shaded. Counties which produce little house coal show a high percentage of run of mine and appear heavily shaded or black. For the country as a whole the shipments of bituminous in 1927 consisted of 50 per cent run of mine, 29 per cent prepared sizes, and 21 per cent screenings or slack.

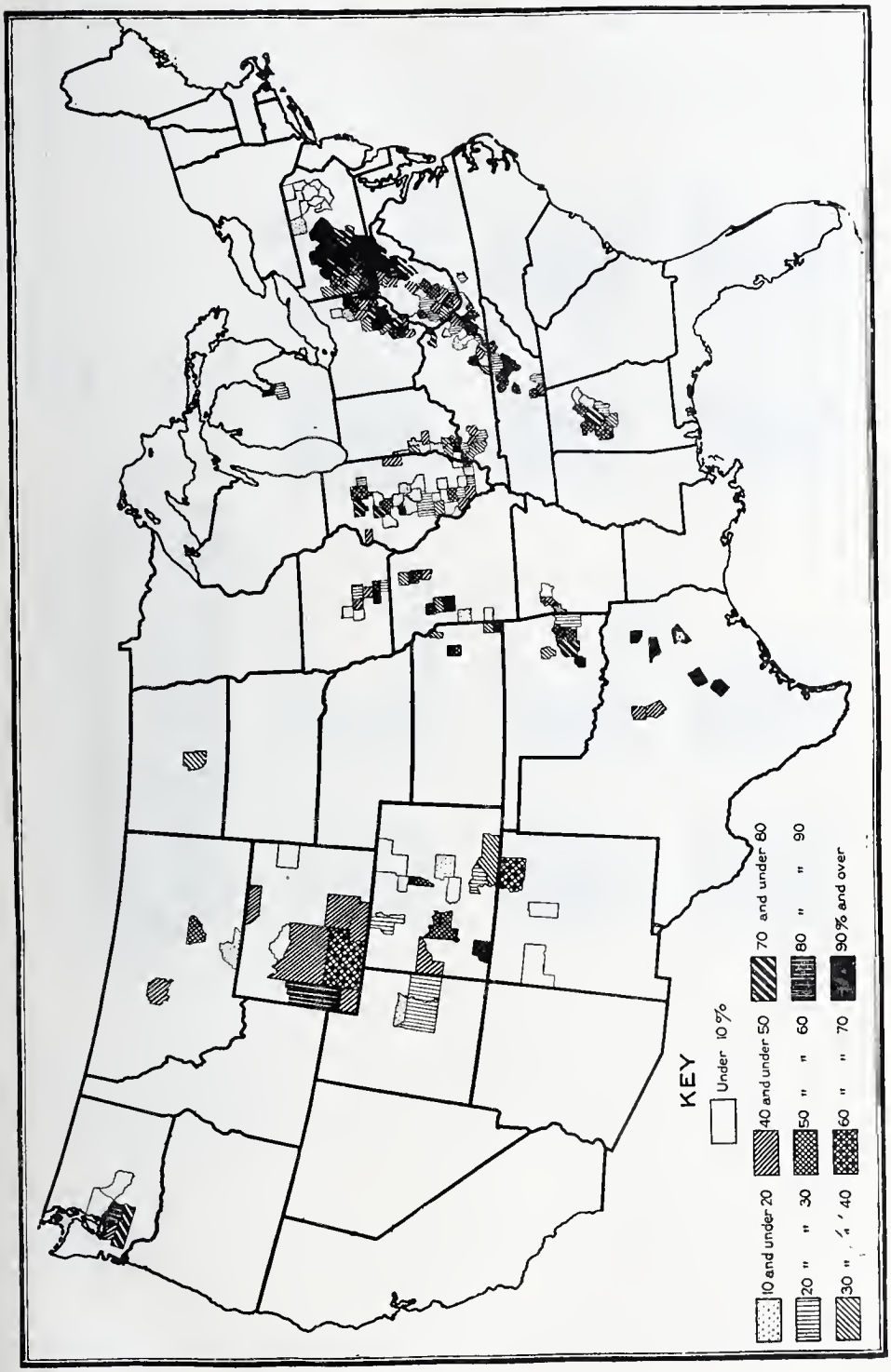
KEY
Under 10%
10 and under 20
20 " " 30
30 " " 40
40 and under 50
50 " " 60
60 " " 70
70 and under 80
80 " " 90
90% and over

FIG. 2

SEASONAL CHARACTER OF CONSUMPTION

Even coal men often fail to appreciate fully the seasonal character of the consumption. Figure 3 shows typical fluctuations in the monthly requirements of certain major groups of consumers. The

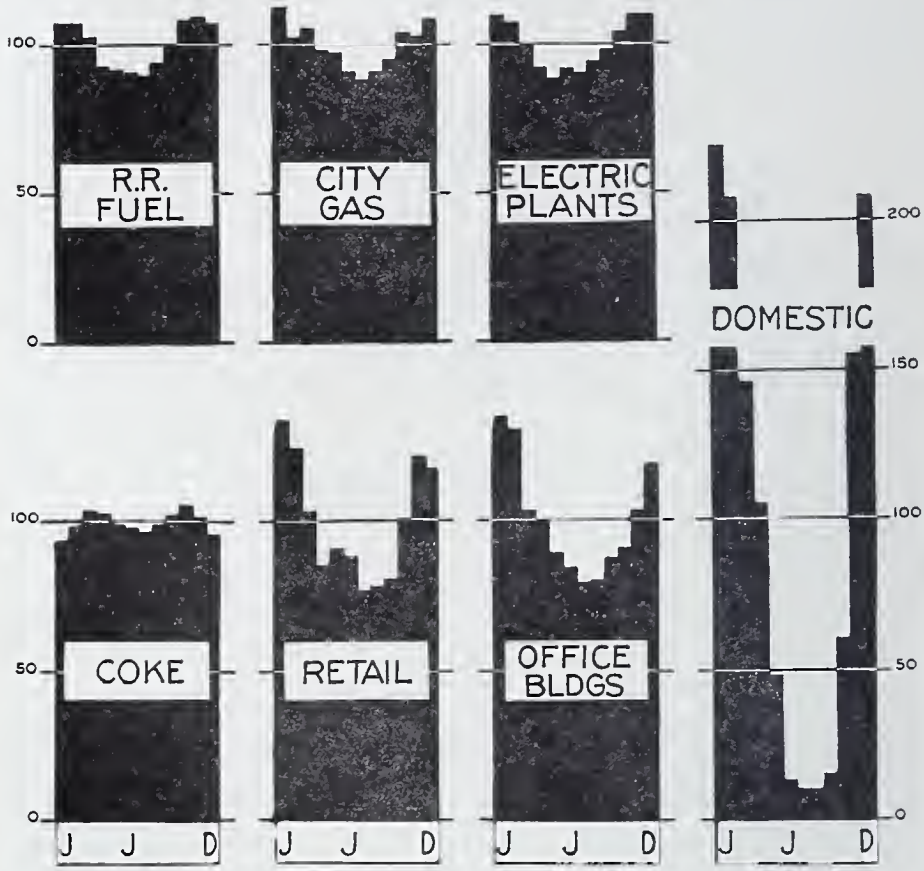

FIG. 3. THE SEASONAL CHARACTER OF COAL CONSUMPTION

The seasonal variations in the requirements of certain classes of consumers are shown for a typical year. The daily rate for each month is represented as an index number, the average for the year being taken as 100.

Reproduced from "Off season purchase and storage of railroad fuel," by F. G. Tryon and W. F. McKenney. *International Railway Fuel Association Proceedings, 1924*, pp. 215–237.

railroads use more fuel in winter than in summer, partly because of differences in the volume of traffic, but chiefly because of larger unit consumption in cold weather. Much the same type of curve is shown by the city gas plants and electric central stations. Even the consumption by general manufacturing industries is greater in winter than

in summer because of the large amount of fuel required to heat factory buildings.

The extreme of seasonal fluctuation is shown by the domestic consumption. The deliveries of retail dealers are also sharply seasonal, and would be more so were it not for the steadying influence of the small steam trade and the custom followed by many householders of laying in their winter's supply during the summer.

The seasonal character of consumption is emphasized because it affects all projects for the processing of coal. In proportion as the demand for the product is seasonal, the load factor is depressed and the burden of storing both the processed fuel and the by-products is increased.

CONSUMPTION BY USES IN A TYPICAL YEAR

A cross section of the demand in a typical year of industrial activity is given in Figure 4 and Table I. With certain exceptions that will be referred to later, data are used covering the active year 1926 rather than either 1927 or 1928, which were marked by a slight recession in industrial activity.

By far the largest consumers are the steam railroads which take 27.7 per cent of the total. This includes not only locomotive coal—amounting to 128,000,000 tons or 24.7 per cent of the grand total—but also about 15,000,000 tons used for shops, roundhouses, stations, and office buildings.

Next in order are the coke ovens, which absorb 16 per cent of the total. In 1926 they consumed 82,870,000 tons of coal, of which 63,600,000 tons was charged in by-product ovens. Since 1926, however, many new by-product ovens have been built, and the figure put down as the by-product consumption in Table I is 68,870,000 tons, the rate maintained in the first 10 months of 1928. Indeed, during November, 1928, the by-product plants were consuming coal at the rate of 72,000,000 tons a year.[1]

The electric utilities, which rank next in importance, consume less than might be expected because of the high thermal efficiencies that they have now attained. In 1927 their consumption of bituminous coal touched 39,770,000 tons, or 7.7 per cent of the total.

[1] Tryon, F. G., Rogers, H. O., and Bennit, H. L. Coke and By-Products; Mineral Resources, 1926, Part II, Bureau of Mines, pp. 614–615, 618–620; Monthly Coke Report, No. 9, page 3.

TABLE I

CONSUMPTION OF BITUMINOUS COAL BY USES IN A TYPICAL YEAR OF INDUSTRIAL ACTIVITY

(In general the data cover 1926, the latest year in which general business in the United States was conspicuously active. For general manufacturing, however, it is necessary to use 1923, the latest year covered by the Census of Manufactures, which fortunately was also a year of industrial activity. For certain other groups of consumers, figures for 1927 are used as being more representative than 1926. The result, though not agreeing with the total for any single year, is typical of present-day conditions when general business is prosperous.)

ITEM	YEAR	NET TONS CONSUMED		PER CENT OF TOTAL	
Railroad fuel (all steam roads)*	1926				
Locomotive fuel		127,900,000		24.7	
All other (shops, stations, etc.)		15,200,000		3.0	
Total			143,100,000		27.7
Coke ovens†	1926				
By-product		68,870,000		13.3	
Beehive		14,000,000		2.7	
Total			82,870,000		16.0
Electric utilities	1927		39,770,000		7.7
Steel works‡	1926				
Gas coal		10,300,000		2.0	
Steam coal		17,800,000		3.4	
Total			28,100,000		5.4
General manufacturing§	1923				
Stone, clay, and glass products		24,030,000		4.6	
Metals and metal products other than steel works**		18,202,000		3.5	
Food products (not including ice)		11,647,000		2.3	
Chemicals and fertilizers		10,623,000		2.1	
Paper, pulp, and printing		10,481,000		2.0	
Textiles and their products		8,846,000		1.7	
Petroleum refining		3,890,000		0.8	
Leather and rubber products		3,915,000		0.8	
Lumber and wood products		3,673,000		0.7	
Miscellaneous manufacturing industries		2,755,000		0.5	
Ice		2,699,000		0.5	
Total			100,761,000		19.5
Coal gas and water gas‡‡	1925		5,263,000		1.0
Coal mine fuel	1926		5,728,000		1.1

TABLE I—*Continued*

ITEM	YEAR	NET TONS CONSUMED		PER CENT OF TOTAL	
Mines and quarries other than coal	1919		4,190,000		0.8
Bunker	1927				
Foreign		4,581,000		0.9	
Domestic (incomplete)		2,970,000		0.6	
Total			7,551,000		1.5
Domestic and all other uses‡‡	1926–1927		100,000,000		19.3
Grand total			517,333,000		100.0

* Based on records of Interstate Commerce Commission covering Class I roads. Includes an allowance for Class II and III roads, and switching and terminal companies.

† The figure for coke ovens represents the total consumed in the active year 1926, subdivided, however, between beehive and by-product so as to allow for the progress in constructing new by-product ovens in 1927 and 1928.

‡ Estimated from quarterly reports on stocks and consumption to the Bureau of Mines.

§ Other than steel, coke, gas, and railroad repair shops. From the Census of Manufactures.

** Includes motor vehicles.

†† Bituminous coal used for gas making, not including that charged in by-product ovens operated by city gas companies.

‡‡ Includes the heating of large buildings other than factories, such as hotels, apartments, stores, offices, theaters, garages and service stations, and also a number of other items that cannot be separated, such as water works, construction industry, threshing, U. S. Navy, central heating plants, laundries, and very small industrial consumers not covered by the Census of Manufactures. Because of the inclusion of these items, the total for this group is not comparable with the estimates of consumption for "domestic use" hitherto published.

When business conditions are favorable, the iron and steel industry consumes about 10,300,000 tons of gas coal and 17,500,000 tons of steam coal, together making about 5.4 per cent of the United States total. This covers the requirements of blast furnaces, steel works, and rolling mills but does not, however, embrace the coal used by the furnaces in the form of coke which amounts to 59,000,000 tons. Including coal for coking, the total requirements of the iron and steel industry when business is active now amount to 88,000,000 tons annually. Small wonder that the demand for bituminous coal is so greatly affected by the booms and slumps of general business, as recorded in the production of pig iron.

The next item in the table covers the general manufacturing industries not including the coke ovens, steel works, gas plants, and railroad shops which are found elsewhere in the table. For this item, it is necessary to use 1923, the latest year covered by the census of manufactures. Fortunately, 1923 was also a year of marked industrial activity, and the tonnages set down are at least as high as they would be for any subsequent year. The class as a whole consumes in round numbers 100,000,000 tons of bituminous coal, or 19.5 per cent of the grand total. In the diagram, this consumption is shown broken down into 11 principal groups of industries. Chief in importance is the stone, clay, and glass products group, which accounts for 4.6 per cent of the consumption. This is followed by the metals and metal products (other than steel works) with 3.5 per cent, by the food products with 2.3 per cent, and so on. It is worth noting that the manufacturing groups consuming the largest tonnages of coal are those in which fuel is required extensively for heating operations. The last group shown is the manufacture of ice which in 1923 consumed 2,699,000 tons, a quantity that is destined to shrink as the ice plants purchase more and more of their power from central stations.

The importance of the requirements of coal gas and water gas plants is greater than would be indicated by the tonnage consumed which amounts to 5,263,000 tons or barely 1 per cent of the total supply. This figure includes only bituminous coal for carbonization in gas retorts or for direct conversion into water gas, both of which uses require coals of special quality.

Other small items are fuel for coal mines, for other mines and quarries and for ship's bunkers. Each of these accounts for approximately 1 per cent of the total.

There remains a residue designated as "domestic and other purposes" which amounts to 100,000,000 tons, or 19.3 per cent of the grand total. This item is obtained by subtracting the other known items from the known total, the result being checked against all available information as to the magnitude of the uses which it includes. Its largest single element is the demand for domestic purposes which, according to studies of Lesher and Thom, in 1917 amounted to 57,104,000 tons.[1] Such information on the retail coal trade as is available indicates that since 1917 there has been a decided

[1] Lesher, C. E., Coal, Part B, Mineral Resources of the United States, 1917, Part II, U. S. Geol. Survey, p. 1254.

increase in the bituminous coal used for domestic purposes, but how large is the increase is not known. It is known that the item of 100,000,000 tons besides the heating of homes and apartments, includes the heating of all large buildings other than factories, such as: hotels, stores, offices, theaters, schools, public buildings, garages,

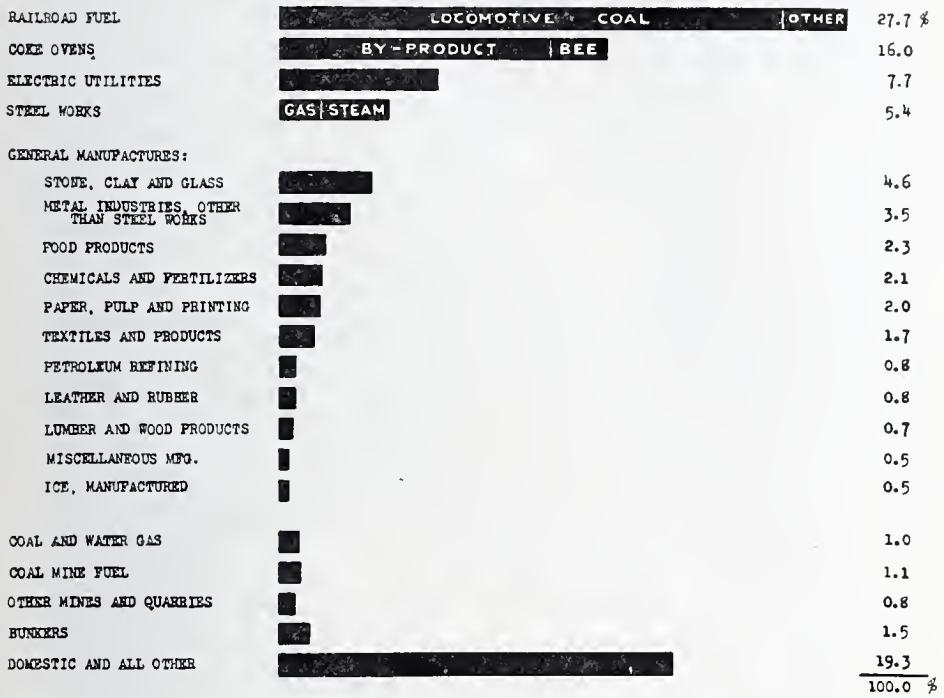

FIG. 4. CONSUMPTION OF BITUMINOUS COAL BY USES IN A YEAR OF INDUSTRIAL ACTIVITY

The data for general manufactures used in preparing this chart represent 1923, the last year covered by the Census of Manufactures; those for railroads, coal mine fuel, and steel works represent 1926. For the electric utilities, bunkers, and "domestic and all other" 1927 data have been used as being more typical than 1926. The figure for coke ovens represents the total consumed in the active year 1926, subdivided, however, between beehive and by-product so as to allow for the progress in constructing new by-product ovens in 1927 and 1928.

Note that the item "domestic and all other" includes, besides houses, the heating of large buildings other than factories, such as hotels, apartments, stores, offices, theaters, garages and service stations.

service stations, steam laundries, etc. It also includes a number of other items on which accurate data are not available, such as the requirements of city water works, central heating plants, the construction industry, threshing engines, the United States Navy, and the very small industrial consumers whose products are valued at

less than $5,000.00 a year and who are therefore not covered by the Census of Manufactures.

TABLE II

CONSUMPTION OF THE 25 LARGEST INDIVIDUAL INDUSTRIES IN THE GROUP OF GENERAL MANUFACTURING PLANTS (OTHER THAN STEEL, COKE, AND GAS WORKS AND RAILROAD REPAIR SHOPS), 1923

(Data from the census of manufactures of 1923. The figures include anthracite as well as bituminous coal.)

	NET TONS
1. Clay products and pottery	10,635,000
2. Paper and wood pulp	10,510,000
3. Cement	8,787,000
4. Chemicals, including coal-tar products	4,997,000
5. Petroleum refining	4,898,000
6. Foundry and machine shops	4,302,000
7. Cotton goods	4,053,000
8. Slaughtering and meat packing	3,922,000
9. Glass	3,146,000
10. Ice, manufactured	2,896,000
11. Automobiles, including bodies and parts	2,629,000
12. Rubber goods	2,123,000
13. Zinc smelting and refining	1,978,000
14. Woolen and worsted goods	1,774,000
15. Lumber and timber products	1,625,000
16. Butter, cheese and condensed milk	1,432,000
17. Electrical machinery, apparatus and supplies	1,418,000
18. Leather, tanned and finished	1,399,000
19. Dyeing and finishing textiles	1,298,000
20. Glucose and starch	1,208,000
21. Bread and other bakery products	1,177,000
22. Copper smelting and refining	1,116,000
23. Furniture and refrigerators	1,130,000
24. Flour mill and grist mill products	1,043,000
25. Beverages	1,038,000
All other (265) industries	20,227,000
Total manufacturing other than steel works, coke and gas plants and railroad repair shops	100,761,000

A further analysis of the requirements for general manufacturing industries is afforded by Table II which shows the consumption of the 25 leading individual industries as reported by the census of 1923.[1]

[1] Bureau of the Census, Biennial Census of Manufactures, 1923, pp. 1216–1242.

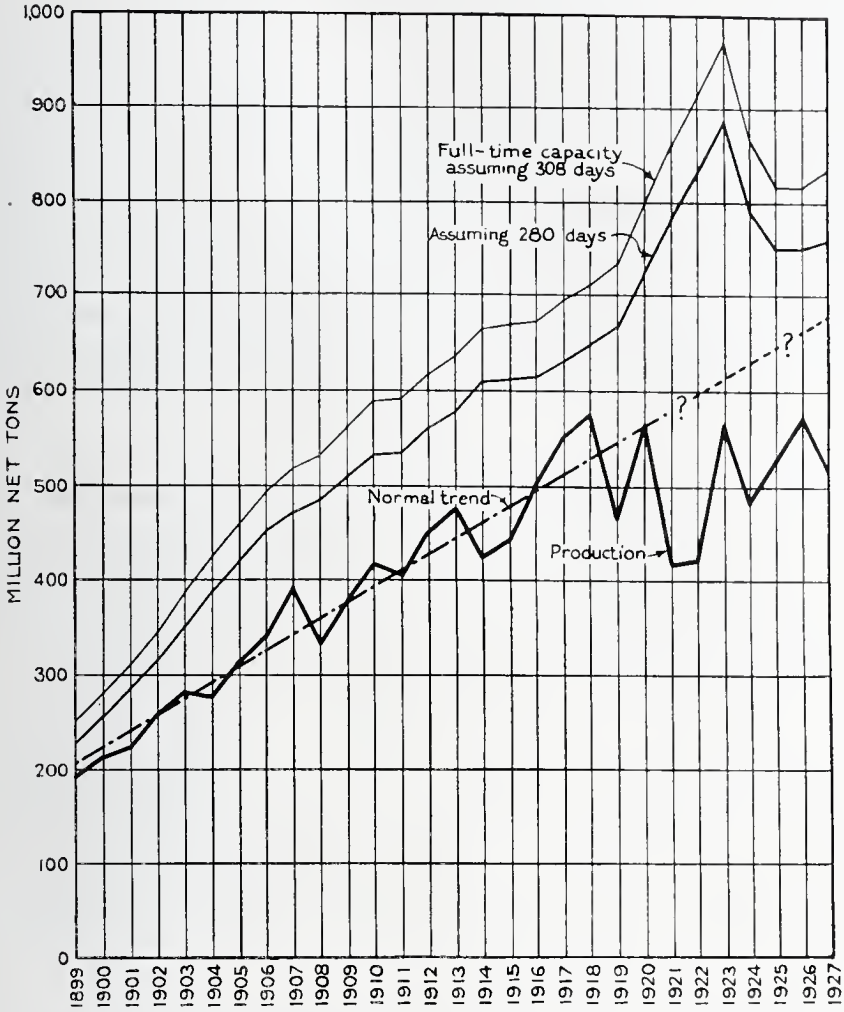

FIG. 5. THE TREND OF BITUMINOUS COAL PRODUCTION AND OF MINE CAPACITY IN THE UNITED STATES, 1890–1927

For the twenty years from 1899 to 1919, according to studies of Professor E. E. Day for the Harvard Economic Service, the production of bituminous coal grew at the average rate of 16,800,000 tons a year. Since then it has shown little or no increase. In the diagram Day's line of "normal trend" for the period up to 1919 is projected through the post-war period, in order to bring out the striking change in the line of actual production. Had the former rate of growth continued, the production in 1927 would have been 160,000,000 tons greater than it actually was.

At the same time that the former growth of demand was checked, the capacity increased sharply and by 1923 the excess of capacity over production was so marked that a readjustment became inevitable.

TREND OF DEMAND SINCE THE WAR

To the practical coal man perhaps the most significant fact about the consumption is that the rapid growth which was so conspicuous in the period before the war has been checked. Whereas in the twenty years from 1899 to 1919 the production of bituminous coal grew at the average rate of 16,800,000 tons a year, since then it has shown no increase whatever. The change is brought out graphically in Figure 5. Had the former rate of growth as indicated by pre-war experience continued since the war, the demand in 1927 would have been some 680,000,000 tons. The actual production in that year was 517,000,000 tons. This striking change in the demand came

TABLE III

PER CENT OF INCREASE OR DECREASE IN ANNUAL SUPPLY OF COAL, OIL, GAS AND WATER POWER, 1913 TO 1927 AND 1917 TO 1927*

	1913 TO 1927	1917 TO 1927
	per cent	*per cent*
Bituminous coal consumed	+9	−6
Anthracite consumed	−12	−20
Total coal	+5	−8
Oil produced	+262	+169
Natural gas produced	+148	+82
Water power produced	+186	+110
Total energy	+38	+18

* For detailed data see U. S. Bureau of Mines Coal 1926, pp. 437, 451–453, 458, and Weekly Coal Report No. 593, pp. 5–6.

upon the industry at a time when productive facilities were rapidly expanding under the influence of the high prices of fuel in 1917–1918, 1920, 1922–1923. The combination of increasing mine capacity and arrested demand, as illustrated by the diagram, produced a condition such that readjustment was inevitable. Between 1923 and 1927 a total of 110,000 miners lost their jobs, 2,320 commercial mines were forced to close and mine capacity was reduced by 135,000,000 tons. The capacity now in operation does not greatly exceed what might have been required had the former rate of increase in demand continued. Actually, because of the checking of demand, the disparity between mine capacity and production is still greater than before the war.

It is therefore a matter of the greatest importance for the bituminous coal industry to study the causes underlying the changing trend of consumption.

Rapid growth of the other sources of energy. A factor in the slowing down of coal demand has been the rapid rise of the alternative sources of power (Table III). While the consumption of bituminous coal in 1927 was actually 6 per cent less than in 1917 the production of oil was 169 per cent greater, that of natural gas 82 per cent greater, and that of water power 110 per cent greater. The total supply of the raw materials of energy shows an increase of 18 per cent for the 10-year period, but the increase has come entirely from sources other than coal. As consumption in 1917 was undoubtedly stimu-

TABLE IV

PER CENT OF THE ANNUAL SUPPLY OF ENERGY FROM MINERAL FUELS AND WATER POWER IN THE UNITED STATES*

YEAR	ANTHRACITE PRODUCTION	BITUMINOUS COAL PRODUCTION	OIL PRODUCTION	OIL IMPORTED	NATURAL GAS PRODUCTION	WATER POWER PRODUCTION	TOTAL ENERGY
1899	22.1	68.2	4.6		3.2	1.9	100.0
1909	15.5	70.2	7.8		3.6	2.9	100.0
1913	14.0	70.3	8.4	0.6	3.5	3.2	100.0
1917	12.9	68.8	9.6	0.8	4.1	3.8	100.0
1927	8.8	54.8	21.9	1.4	6.3	6.8	100.0

* As these figures do not include work animals, firewood, and windmills, they differ slightly from those given in Figure 1.

lated by the war, perhaps a fairer basis of comparison is afforded by 1913. But even starting with 1913, the competitive sources show a rate of increase that far outstrips coal. From 1913 to 1927, the consumption of bituminous coal increased 9 per cent. (The consumption of anthracite decreased slightly.) During the same period oil production increased 262 per cent, natural gas 148 per cent, and water power 186 per cent.

Clearly much of this extraordinary increase in the other sources of power does not represent displacement of coal. The water power and most of the natural gas are meeting a need that could be supplied by coal, but the refined products of petroleum and even a large part of the fuel oil have been used for purposes that raw coal could not meet. Even fuel for internal combustion engines, however, involves

an invisible competition with coal; had not gasoline been available the need of a system of light transportation to supplement the railroads would doubtless have stimulated alternative means, such as electric traction driven by coal generated electricity.

The unequal growth of the several forms of power has brought about a remarkable shift in the sources of the country's energy supply. In 1913, bituminous coal furnished 70.3 per cent of the total energy derived from mineral fuels and water power; in 1927, as Table IV shows, its share had fallen to 54.8 per cent.

Advances in fuel efficiency. Of equal importance in slowing down the growth of the demand has been the great improvement in the efficiency of fuel utilization. Wherever records of fuel performance are kept, a story of reduced consumption per unit of product is found, particularly over the period since 1917. The rate of improvement has naturally varied with the industry. It has been most marked in the field of power generation, but even those uses involving the direct application of heat show advances in lesser degree. This subject, however, can best be treated by considering individual industries.

TREND OF RAILROAD FUEL CONSUMPTION

The trend of demand becomes clearer if one considers not the total but the demand of the principal consuming groups, particularly for different grades of coal. If this is done, it appears that while consumption for some uses is holding its own, other uses show a sharp decline and still others a substantial increase. In general, consumption for what may be called the "power uses" is decreasing, while that for the "heat uses" shows a tendency to increase.

Typical of the power uses is the consumption of locomotive fuel, which, it will be remembered, absorbs about 24 per cent of the supply of bituminous coal. Figure 6 is designed to bring out the trends of the three principal factors that control consumption: (1) The physical volume of rail transportion, (2) the progress of fuel efficiency, and (3) the use of competitive fuels. The resultant of these factors is the aggregate consumption of bituminous coal, shown by the heavy zigzag line in the lower half of the diagram.[1]

[1] The figures of coal consumption by locomotives for 1904 to 1916 used in Fig. 6 were compiled by the authors from unpublished reports made by the individual carriers to the Interstate Commerce Commission and will be published in detail elsewhere. Other primary data are taken from Interstate Commerce Commission, Statistics of Railways of the United States.

The trend of the physical volume of rail transportation is indicated in the upper half of the diagram. Both freight ton-miles and passenger-train car-miles have been increasing, and the curve of total transportation units which combines the two shows a substantial gain even in the period since the war, interrupted only by the occasional depressions of general business.

The increase in traffic, however, has been offset by the marked improvement in fuel efficiency. The curve of pounds of coal per transportation unit declines rapidly from 1912 to 1916, halts during the period of disturbed coal supply from 1917 to 1922, and in 1923 again turns sharply downward.[1] In spite of the advances already made there is room for further improvement in fuel efficiency in bringing average performance nearer the level of what the best locomotives have already indicated is possible. The average consumption in the freight service in 1927 was 131 pounds per 1000 gross ton-miles, but the Union Pacific Railroad reports a locomotive that uses only 70 pounds.[2]

The competition of other fuels in the railroad fuel market is indicated by the curves for anthracite and fuel oil consumption. The increase in oil has been partly offset by a decline in the use of hard coal by the anthracite carriers, who have turned more and more to bituminous coal, releasing anthracite for uses to which it is especially adapted. The consumption of oil increased sharply in 1923, but has shown no material change in the last three years.

The net result of the several factors has been an actual decline in the total consumption of bituminous coal. Although the railroads in 1927 did 9 per cent more work than in 1917 they required 13 per cent less bituminous coal.

TRENDS OF CONSUMPTION IN THE IRON AND STEEL INDUSTRY

A similar condition is shown by the iron and steel industry, which absorbs directly or indirectly 16 per cent of the total supply of

[1] This ratio (represented by the dotted line in the upper diagram) is obtained by dividing the total quantity of locomotive fuel used for freight, passenger, and all other services (including the coal equivalent of oil) by the sum of the revenue ton-miles and the passenger-train car-miles $\times$ 40. It is used in place of the more accurate figure of pounds per one thousand gross ton-miles or pounds per passenger-train car-mile because it can be calculated for the pre-war years, thereby indicating the trend over a longer period. The curve as plotted is a 3-year moving average of the annual observations.

[2] McAuliffe, E., Railway Fuel: New York, 1927, p. 323.

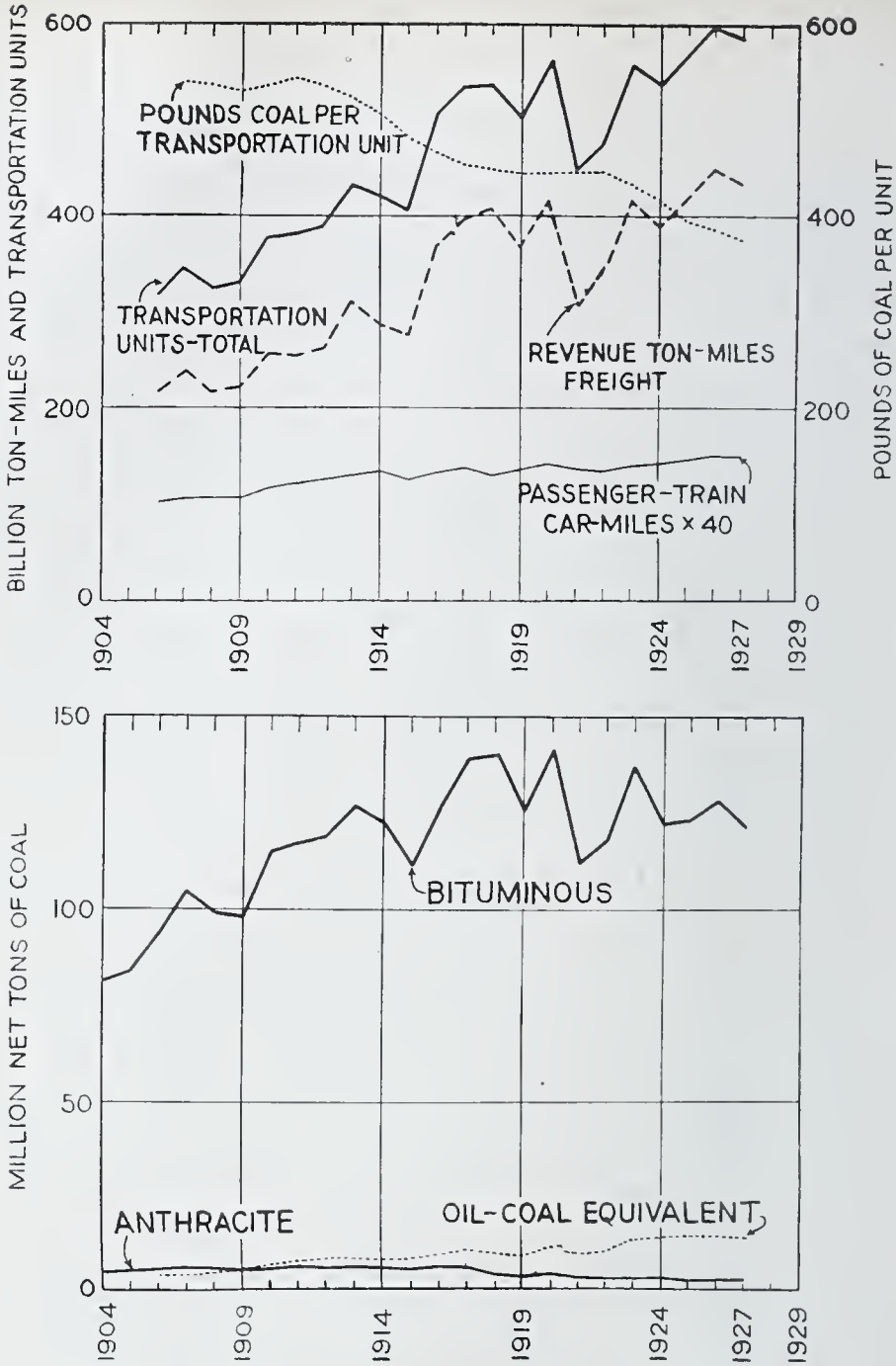

Fig. 6. Trends in Consumption of Fuel by Steam Locomotives

As shown by the upper diagram, the volume of transportation service has continued to grow since the War. The revenue ton-miles have increased notably, and even the passenger-train car miles show some increase, in spite of the competition of motor vehicles. If the two are added together (first multiplying the passenger-train car miles by 40 in order to make them comparable in terms of fuel consumption), the result may be termed "total units of transportation." This is represented by the heavy black line at the top which shows a substantial gain.

At the same time, the consumption of fuel per transportation unit has been declining. This improvement in fuel efficiency plus an increase in the quantity of fuel oil used has resulted in a net decrease in the quantity of bituminous coal consumed by the carriers.

bituminous coal. (See Fig. 7.) The volume of the product is increasing, but advances in fuel efficiency have brought about an actual reduction in the total consumption of coal.

The volume of the product may be measured by adding together the tonnage of pig iron and half of the tonnage of steel, since it requires about half as much fuel to convert the pig into finished rolled products as it does to convert the ore into pig. The curve representing the two combined shows a very large increase in volume of product since 1913. In comparison with the war period many of the post-war years show a decrease, but it must be remembered that from 1916 to 1918 the production of steel was stimulated by the demand for munitions. Even on this basis, however, the active year 1926 shows an increase of 4 per cent over 1918.

Meanwhile, rapid progress has been made in fuel economy. In 1904 the ratio of tonnage of coal used (including the equivalent of fuel oil) to tonnage of product was 2.01; in 1914 it was 1.8; and by 1927 it had fallen to about 1.4. The reduction in unit fuel consumption would appear still greater if it were possible to include data on natural gas, which has been declining in relative importance.[1] The largest element in this saving has undoubtedly been the substitution of by-product for beehive coke. The gas, tar, light oil, and breeze recovered at by-product plants in 1927 had a heat value equivalent to 15,600,000 tons of raw coal, as against 700,000 tons in 1904. It should be noted that the economies resulting from by-product coking approach a limit as the displacement of beehive coke becomes more nearly complete.

Displacement of coal by fuel oil in this industry has been very small.

The net result of the several factors has been a sharp reduction in the total consumption of both gas and steam coal and coking coal by the iron and steel industry. In comparison with 1916, the active year 1926 shows an increase of 2,700,000 tons in volume of product but a decrease of 15,000,000 tons in the consumption of bituminous coal.[2]

[1] Accurate figures on the consumption of natural gas by the iron and steel industry are not available. It is known, however, that the total consumption for all industrial purposes in Pennsylvania declined from 121,000,000,000 cubic feet in 1906 to 63,000,000,000 in 1927.

[2] The data on fuel consumption in the iron and steel industry are derived from the annual coke reports of the U. S. Geological Survey and Bureau of

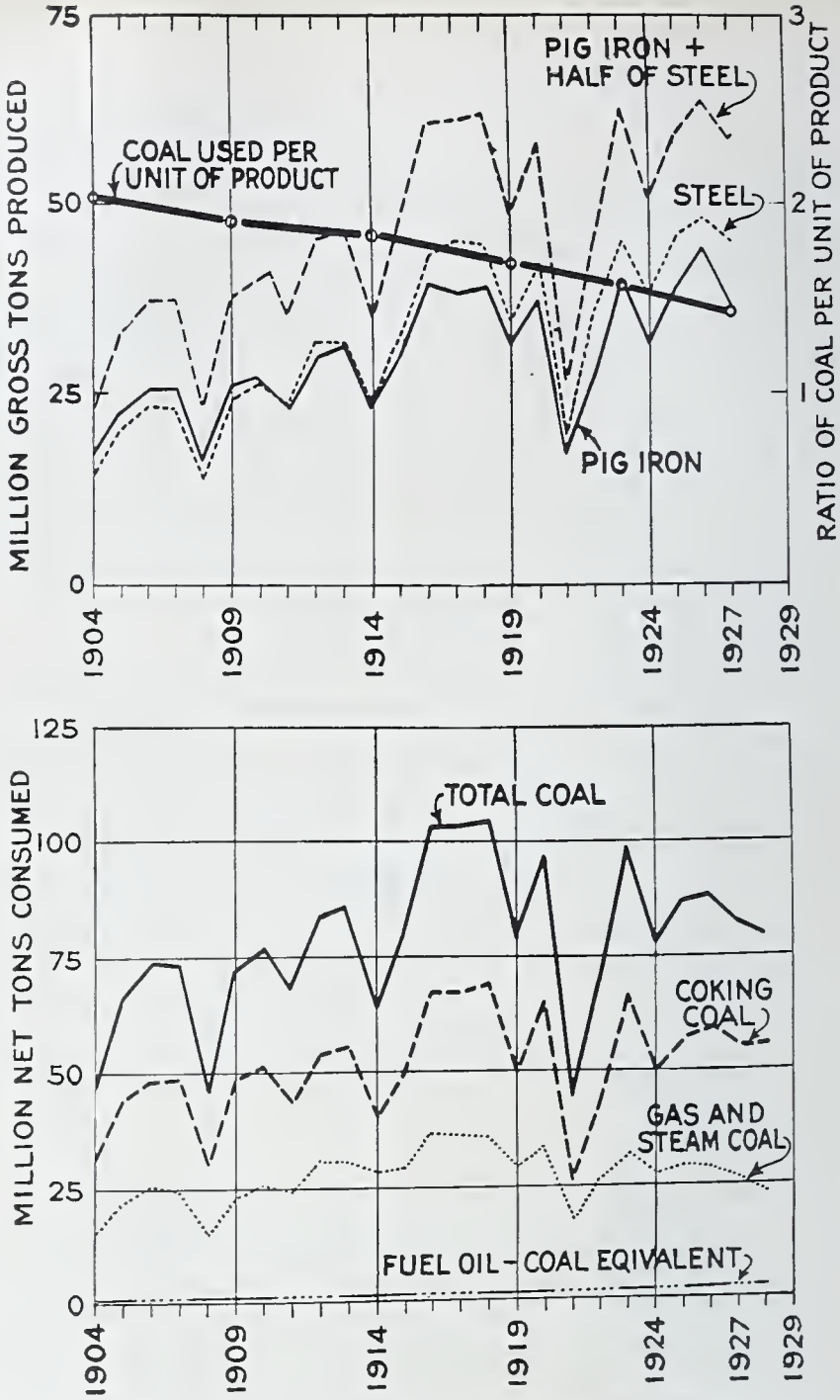

Fig. 7. Trends in Consumption of Fuel by Blast Furnaces, Steel Works, and Rolling Mills

The upward trend of the production of metal in the iron and steel industry has continued since the War, though the rate of increase has been less rapid than before. Production of steel shows a greater increase than that of pig iron, because of the growing use of scrap. By adding the tonnage of pig iron and half of the steel, one gets a measure of the total volume of product from the viewpoint of fuel consumption, and as shown by the curve, this established a new record in 1926.

In the meantime, the consumption of coal per unit of product (including coal equivalent of oil but not of gas, for which data are not available) has been declining.

As a result of these tendencies the total consumption of coal in iron and steel manufacture has declined since the War.

TREND OF CONSUMPTION OF THE ELECTRIC UTILITIES

Even more striking have been the changes in the consumption of the electric utilities (See Fig. 8.) The business of the utilities has grown by leaps and bounds like a sum at interest compounding at the rate of 10 per cent. In the last 25 years the total production of electric power by central stations and electric railways has increased nineteen fold. Part of the increase is due to the development of hydropower; but, as the diagram shows, the production of fuel power has risen from 4,000,000,000 kw.h. in 1902 to about 52,000,000,000 in 1928, an increase of thirteenfold. The consumption of coal has increased during the same period but in much smaller ratio. In 1902 the utilities used, in round numbers, 11,000,000 tons; in 1928, they used 41,000,000, an increase of less than fourfold against the thirteenfold increase in power production.

This astonishing result has been made possible by improvements in fuel efficiency. In 1902 the average consumption per kilowatt hour was about 6.6 pounds. By 1917 this had been cut to 3.3 pounds. Particularly rapid progress has been made since the War, and in 1927 the average fell to 1.83 pounds. Even this is much above the performance of the best plants today, and one station on the Ohio River below Cincinnati has touched a record of 0.86 pound per kilowatt hour generated.[1]

Competition of oil and natural gas has been a minor factor in the coal requirements of the utilities. The use of these other fuels reached its maximum in 1924, when oil and gas equivalent to 5,500,000 tons of coal were consumed. Since then the consumption of oil has been declining, and the total of oil and gas in 1927 was equivalent to but 4,022,000 tons of coal or 9 per cent of the total fuel consumption of the utilities.

The net result of these factors has been to hold the total coal consumption of the utilities virtually constant for the last four years. (See Fig. 8.) Indeed, the consumption for the first ten months of 1928 was slightly less than for the corresponding period of 1927.[2]

Mines, the reports of the American Iron and Steel Institute, and the Census of Manufactures. Consumption of gas and steam coal is estimated for the inter-census years from the known production of iron and steel. Data will be published elsewhere in detail.

[1] DeForest, C. W., 12495 B.T.U. per net Kilowatt Hour: *Elec. World*, February 12, 1927, p. 341.

[2] For data on power production and fuel consumption see Horton, A. H., Developed and Potential Water Power in the United States and Production

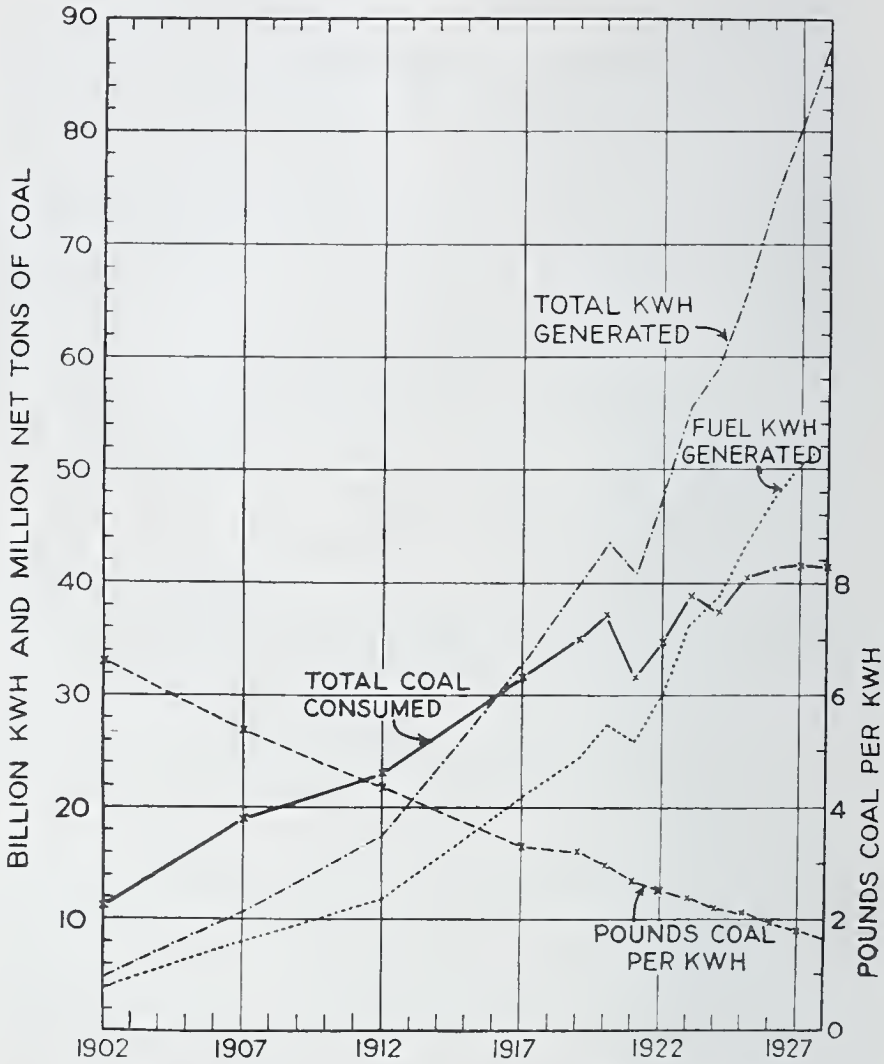

FIG. 8. TRENDS IN CONSUMPTION OF FUEL BY ELECTRIC POWER PLANTS (PUBLIC UTILITIES)

Beginning with 1919, the data are from the monthly power reports of the U. S. Geological Survey. (See Water Supply Paper 579, p. 198.) Prior to 1919, data are available for the years 1902, 1907, 1912, and 1917, the years covered by the five-year census of the electrical industries made by the federal Bureau of the Census. The census does not separate the kilowatt hours generated by fuels and by water but gives sufficient data on installed capacity of prime movers to permit an approximate separation. The quantity of coal used was reported in 1902 (incomplete) and 1917 (complete), and the cost of fuel was reported in 1902, 1907, 1912, and 1917, from which the total consumption and the pounds per kilowatt hour have been derived. The result, though not precise, is reasonably accurate and indicates the trends.

TREND OF CONSUMPTION IN GENERAL MANUFACTURING

The advances of the electric utilities are naturally reflected in the trend of the general manufacturing industries which have been shutting down their isolated plants and purchasing more and more of their power from central electric stations. Even the plants which

TABLE V

INDEX NUMBERS OF CONSUMPTION OF COAL BY MANUFACTURING INDUSTRIES AND OF THE PHYSICAL VOLUME OF MANUFACTURING PRODUCTION
(1909 rate = 100)

	1909	1914	1919	1923	1926
*Indexes of coal consumption**					
22 "power" industries	100	108	115	92	†
32 "heat" industries	100	114	130	140.4	†
18 "mixed" industries	100	108	136	138.6	†
4 industries affected by abnormal growth or decline:					
Automobile and rubber	100	157	317	382	†
Paper and wood pulp	100	117	145	173	†
Liquors and alcohol	100	113	60	30	†
214 other industries, consuming little coal	100	85	108	97	†
Total, 390 industries*	100	111	128	130	129‡
Index of physical volume of manufacturing production§	100	106	135	164	174

* Includes anthracite as well as bituminous coal, as the two cannot be separated in 1923. Excludes blast furnaces, steel works, and coke and gas plants. Primary data from the Census of Manufactures.

† Data by groups of industries not available.

‡ Subject to revision.

§ From p. 34 of Census Monograph VIII, "The Growth of Manufactures, 1899 to 1923," by Edmund E. Day and Woodlief Thomas. Original data recalculated to 1909 base. Note that these figures include blast furnaces, steel works and coke and gas plants, and are therefore not exactly comparable with those for fuel consumption above. The discrepancy, however, is not serious.

have continued to generate their own power have frequently shown marked improvements in fuel efficiency.[1] From 1909 to 1926 the

of Electricity by Public Utility Power Plants, 1919–1926, in U. S. Geol. Survey, Water Supply Paper 579, 1928, 210 pp.; also monthly power reports, mimeographed.

[1] Gould and Henderson report average savings in fuel consumption of 17 per cent merely by the better utilization of existing equipment. See Even Better Steam Generation, Fuel Engineering Co. of New York, 1927, pp. 4, 30.

physical volume of production of manufacturing goods increased 74 per cent, but the consumption of coal in manufacturing increased only about 29 per cent (Table V). In fact, since 1919 the aggregate consumption in manufacturing has shown virtually no increase

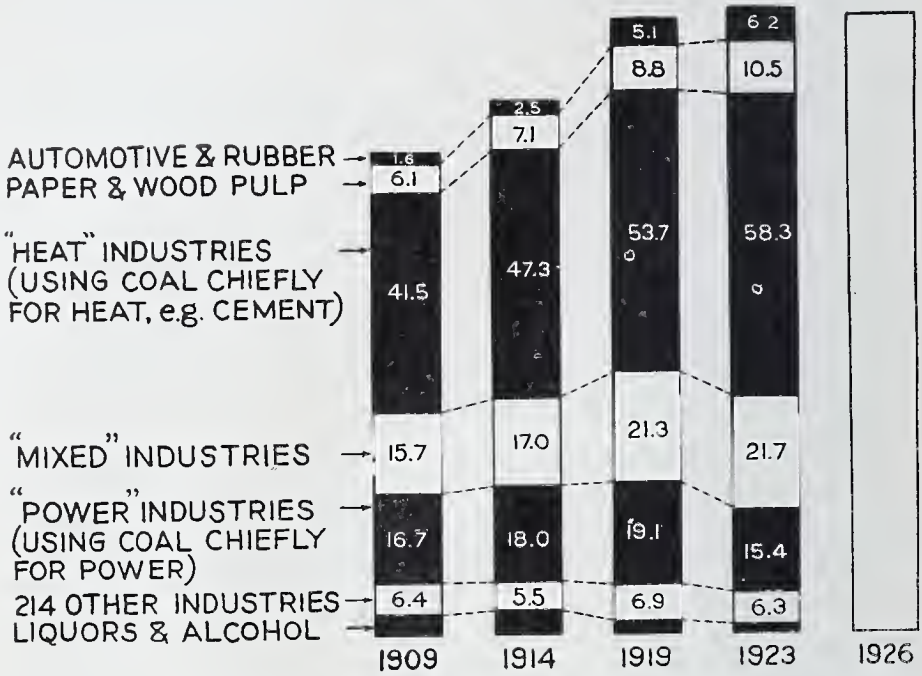

FIG. 9. CONSUMPTION OF COAL BY GENERAL MANUFACTURING PLANTS (NOT INCLUDING STEEL WORKS, COKE AND GAS PLANTS)

The Census of Manufactures gives the coal consumed in 1909, 1914, 1919, and 1923 by each of 390 industries. The consumption in 1926 cannot be subdivided, but from various indications, the total appears to be slightly less than 1923.

The figures in the bars represent million net tons of coal, including anthracite as well as bituminous. The 390 census industries are here grouped from the view point of fuel consumption. The automotive and rubber, and paper and wood pulp industries are separated because they have been affected by an abnormal growth, and the liquor industry, because it has been affected by an abnormal decline. The group of "heat" industries shows a large increase in coal consumption, the "mixed" industries a smaller increase, and the "power" industries an actual decrease. This decrease is due largely to the shutting down of factory power plants and the purchase of electric central station power.

although in the meantime the physical volume of the products has risen nearly 30 per cent.

This statement concerning manufacturing as a whole conceals a remarkable change in the relative requirements of the industries using fuel primarily for power and those using it primarily for heat. (See Table V and Fig. 9.) A group of 22 "power industries" of which

cotton textiles are typical, consumed 16.7 million tons of coal in 1909. (See Fig. 9.) During the next 10 years their consumption increased, rising to 19.1 million tons in 1919. Thereafter with the rapid substitution of central station power, their coal requirements declined, reaching 15.4 million in 1923, the latest year for which detailed data by industries are available.

In sharp contrast, a group of 32 "heat industries"—that is, industries consuming fuel chiefly for direct application of heat, such as the manufacture of cement, clay products, glass, and lime—have shown a continuous increase. Their requirements rose from 41.5 million tons in 1909 to 53.7 in 1919 and 58.3 in 1923. A group of 18 "mixed industries" show a trend intermediate between the heat group and the power group.

The automotive industries are shown separately in Figure 9 because their extremely rapid growth would otherwise distort the picture. Including the related manufacture of rubber goods, the consumption of the automotive group grew from 1.6 million in 1909 to 6.2 in 1923. This large increase in fuel consumption falls far short of the increase in the number of cars and trucks produced, which rose from 131,000 in 1909 to 4,020,000 in 1923. Thus, while the coal consumption of the automotive industries increased a little less than fourfold, the volume of production of finished cars increased more than thirtyfold, a result largely made possible by the purchase of central station power. The paper and wood pulp industry and the liquor and alcohol industries are also shown separately in these comparisons, the former because of its rapid growth and the latter because of its notable decline.

This sharp difference in the trend of the fuel requirements of the heat using and power using industries should be considered in any attempt to forecast the future demand for coal.

Changes in Percentage Distribution of the Total

Figure 10 and Table VI bring together the record for all of the principal classes of consumers for the period from 1889 to 1927. When the consumption of each group is shown as a percentage of the total, it is curious how little change has occurred in this period of nearly 40 years. In 1889, locomotive fuel constituted 27.7 per cent of the total bituminous consumption of the country; in 1923, 26.4 per cent; and in 1927, 24.2 per cent. The coke ovens in 1889 consumed 16.7 per cent of the total and in 1923, 16.3 per cent. In 1889

TABLE VI

TREND OF CONSUMPTION OF BITUMINOUS COAL BY THE PRINCIPAL CLASSES OF CONSUMERS IN THE UNITED STATES, 1889–1927

(The purpose of this table is to show the consumption of each of the principal groups over a long enough period to establish the trend. To do this it was necessary to assemble data from all possible sources, many of them unpublished, and piece them together. Where the tonnage consumed was not known it could often be estimated from data on the cost of the fuel consumed or on the physical volume of the product of the industry. To insure comparability certain items have been regrouped so that the figures do not agree exactly with previous compilations for 1915, 1917, 1918 and 1923 or with the percentages in Table I. As they stand the figures are thoroughly comparable from year to year. Subject to revision especially for 1927, as the authors obtain additional data).

	1889	1899	1904	1909	1914	1919	1923	1927*
Million net tons consumed:								
a. Colliery fuel	1.4	3.1	6.3	9.5	10.4	11.1	8.8	4.9
b. Local sales at mines, not shipped†	6.4	7.8	9.6	12.0	12.9	18.1	22.1	21.9
c. Locomotive fuel, all steam roads‡	26.5	53.4	81.0	106.0	117.0	124 7	137.0	121.0
d. Bunkers, vessels in foreign trade§	1.9§	3.8§	5.5§	6.8	8.2	8.2	5.0	4.6
e. Coke ovens, beehive and by-product	15.9	30.2	36.5	59.3	51.6	65 6	84.4	74.4
f. Iron and steel works¶ (Gas coal and steam coal)	5.1	11.8	13.8	20.9	22.2	28.2	30.2	25.3
g. Coal and water gas plants‖	1.9	2.3	3.5	3.8	4.4	4.4	4.9	5.3
h. Electric public utilities**	††	7.6	13.5	18.7	24.6	32.0	35.5	39.8
i. General manufacturing industries‡‡	36.6	70.3	103.5	78.5	88.3	104.8	107.1	104.1
j. Domestic and all other§§				54 7	69.1	84.5	83 9	98.4
Total	95.7	190.3	273.2	370.2	408.7	481.6	518.9	499.7
Per cent of total consumption:								
a. Colliery fuel	1.5%	1.6%	2.3%	2.6%	2.6%	2.3%	1.7%	1.0%
b. Local sales at mines, not shipped	6.7	4.1	3.5	3.2	3.2	3.8	4.3	4.4
c. Locomotive fuel, all steam roads	27.7	28.1	29.7	28.6	28.6	25.9	26.4	24.2

d. Bunkers, vessels in foreign trade	2.0§	2.0§	2.0§	1.9	2.0	1.7	1.0	0.9
e. Coke ovens, beehive and by-product	16.7	15.9	13.4	16.0	12.6	13.6	16.3	14.9
f. Iron and steel works (gas coal and steam coal)	5.3	6.2	5.0	5.7	5.4	5.8	5.8	5.1
g. Coal and water gas plants	2.1	1.2	1.3	1.0	1.1	0.9	0.9	1.1
h. Electric public utilities		4.0	4.9	5.0	6.0	6.7	6.8	7.9
i. General manufacturing industries	38.0	36.9	37.9	21.2	21.6	21.8	20.6	20.8
j. Domestic and all other				14.8	16.9	17.5	16.2	19.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Data for 1927 preliminary.

† Item *b* includes coal used by mine employees and sold for domestic purposes in the vicinity of the mine. It also includes an unknown amount taken by locomotive tenders at the tipple or sold to a nearby factory or power plant. It therefore involves an unknown amount of overlapping with items *c*, *h*, and *i*. Double counting in the total is avoided by an adjustment in item *j* which is obtained by subtracting the sum of all other items from the known total.

‡ Based on reports of the railroads to the Interstate Commerce Commission, those before 1919 not having been previously published. For certain years where only the Class I roads were reported, estimates are included for Class II and III roads and switching and terminal companies.

§ Figures for 1889, 1899 and 1904 are rough estimates, no data being available before 1906.

¶ Figures include all coal used except that charged in coke ovens. Data for 1889 to 1923 from Census of Manufactures (those for 1904 partly estimated); for 1927, from quarterly stock reports to Bureau of Mines.

|| Includes coal for gas making only. Excludes coal charged in by-product coke ovens operated by city gas companies, which is included under item *e*. Data from Census of Manufactures and U. S. Geological Survey reports.

** Includes electric central stations and street railways. Data for 1919 to 1927 from monthly power reports of U. S. Geological Survey, for 1889 to 1914 estimated from quinquennial census of electrical industries.

†† Coal was used for electric power generation as early as 1882, but even by 1889 the quantity consumed must have been small.

‡‡ From the Census of Manufactures excluding coal consumed in coke ovens, iron and steelworks and for gas making at coal and water gas plants. Includes consumption of railroad car shops which is included under railroads in Table I. Figures for 1927 estimated from quarterly stock reports to U. S. Bureau of Mines. No data are available prior to 1909.

§§ Includes heating of large buildings other than factories, and also some non-domestic uses not covered elsewhere. See also item *b* and note †. Obtained by subtracting sum of the other known items from the known total. Because of this it is affected by any errors in the other items and there is evidence that the figure for 1919 (84.5 million tons) is too high, and the figure for 1923 (83.9 million tons) is too low.

the gas and steam coal requirements of the iron and steel works accounted for 5.3 per cent of the total, and in 1927, for 5.1 per cent. The occasional fluctuations in the percentages for coke and steel during the intervening years reflect the periods of business depression which fell with peculiar severity upon the iron and steel industry. The consumption of fuel at bituminous coal mines, never a large item, rose from 1889 to 1914 with the increasing use of power, but

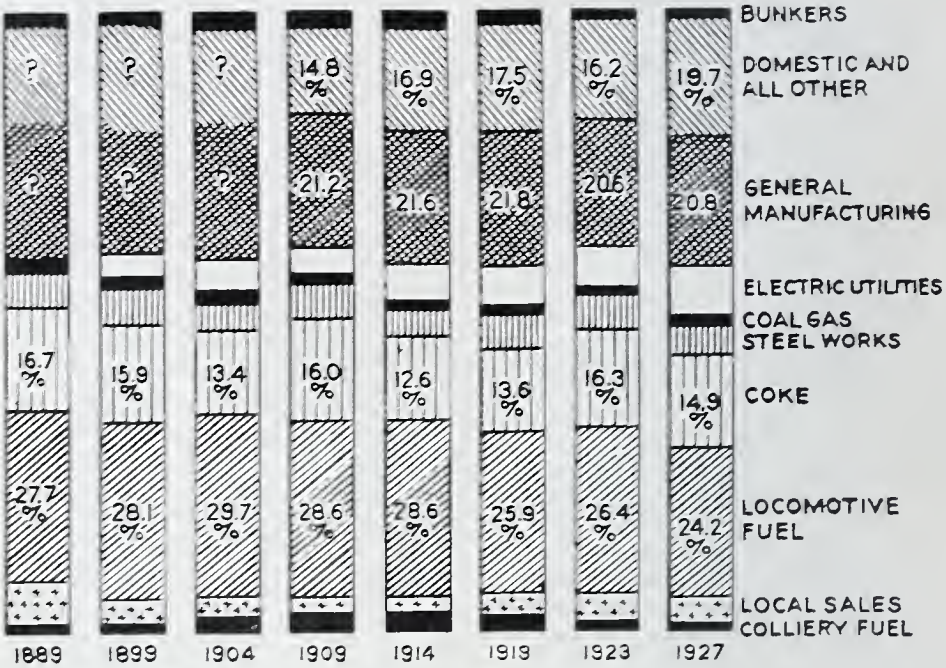

FIG. 10. PER CENT OF THE TOTAL CONSUMPTION OF BITUMINOUS COAL TAKEN BY THE PRINCIPAL CLASSES OF CONSUMERS, 1889–1927

The figures in the bars represent per cent of the total for the year. No separation of the consumption for "general manufacturing" from that for "domestic and all other purposes" can be made before 1909. Note that the figures for locomotive fuel do not include coal for shops, stations, and offices.

since that time has declined as the mines have turned to electric power from central stations. The only group of consumers whose proportion has markedly changed are the electric utilities, and even here the change is less than might be expected because of the extraordinary advances in fuel economy. In 1889, the consumption by electric plants was negligible, but by 1904, when the statistical record becomes trustworthy, they were already taking 4.9 per cent of the grand total. Their maximum reached in 1927 was 7.9 per cent.

The consumption for "general manufacturing" and for "domestic and all other purposes" can not be separated until 1909. In that year, general manufacturing consumed 21.2 per cent of the total, a proportion that has shown curiously little change since. The consumption for domestic and all other purposes does, however, show a fairly steady growth. In 1909 it amounted to 14.8 per cent of the total, and by 1927 this had increased to 19.7 per cent.

Increase in Consumption for Heating Buildings

The consumption of bituminous coal for heating houses and other buildings therefore appears to be increasing. Not only does the percentage devoted to this purpose increase (Fig. 10) but the tonnage actually consumed as well (Table VI).

The data on this subject are less accurate than is desirable, but they seem to justify the following conclusions:

1. Not merely is population increasing, but the per capita consumption of fuel for heating is increasing as well. Higher standards are maintained in American homes, and more fuel is required to keep people warm outside their homes. Children spend a longer period in school, more women work outside their homes, and people spend a larger proportion of their time in places of amusement. All this increases the heating load. The per capita consumption of coal (anthracite as well as bituminous) for "domestic and all other purposes" has increased between 12 and 20 per cent since 1909.

2. Most of this increase in the heating load has gone to bituminous coal rather than anthracite. The larger buildings tend to use bituminous coal, and the anthracite sold is concentrated more and more on the heating of houses, for which purpose it is admirably adapted. The expansion of bituminous coal in this field is doubtless assisted by the increasing proportion of the total population living in apartments.

3. The result is a net increase in the tonnage of bituminous coal used for domestic and other heating, an increase that is reflected in the active interest in screening and sizing which is apparent in the many mining districts.

Consumer Ownership of Mines

It is often asked, "To what extent are consumers of coal protecting their requirements by purchasing mines of their own?" The question

is answered in a special study by the authors, the results of which are summarized in Figure 11.[1] The high prices of coal in the years between 1916 and 1922 did lead many consumers to purchase mines, but the net result of the movement was less than many observers have supposed. In 1913 the consumer-owned mines produced 18.5 per cent of the total output of bituminous coal and in 1926, 22.7 per cent.

FUTURE OF COAL CONSUMPTION

As to the probable trend of demand in the future, the writers venture no prediction although they believe the new data presented in this paper will be helpful to others who may undertake a forecast. It seems clear that the total demand for power and heat in all forms, which is still increasing at a wholesome rate, may be expected to continue its growth. It will not only grow with population, but the per capita consumption will probably increase.

It is also clear that whatever of this total demand for energy is not supplied by oil, gas and water power will fall back upon coal. The possibilities of water power are limited. The great variable, the most uncertain factor in the future of coal, is the consumption of oil and gas. Most observers expect the production of petroleum to decline sooner or later, and when it does a corresponding increase in coal consumption may be anticipated.

As to the factor of fuel economy, all will agree that the present rapid rate of improvement in fuel efficiency is not likely to continue indefinitely. The progress since 1917 is largely a taking up of slack, a general adoption of principles already known to engineers. On the other hand, the advances in efficiency give no promsie of terminating abruptly for there is still room for great improvement in bringing average performance nearer to the level of what the best performance has already indicated is possible.[2]

An analysis of consumption may well close with a quotation from the English economist Jevons, whose famous book on the "Coal Question," published in 1865 forecast successfully the general course of the British coal trade for the next half century. "It is . . . . a

[1] See Tryon, F. G., Kiessling, O. E., and Mann, L., Coal: Mineral Resources of the United States 1926, Part II, Bureau of Mines, pp. 466–475. The complete report by H. O. Rogers and F. G. Tryon will be published elsewhere.

[2] See Tryon, F. G., Kiessling, O. E., and Mann, L., work cited, pp. 449–450.

confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. . . . . As a rule, new modes of economy will lead to an increase of consumption according to a principle recognized in many parallel instances. . . . . If the quantity of coal used in a blast furnace . . . . be diminished in comparison with the yield, the profits of the trade will increase, new

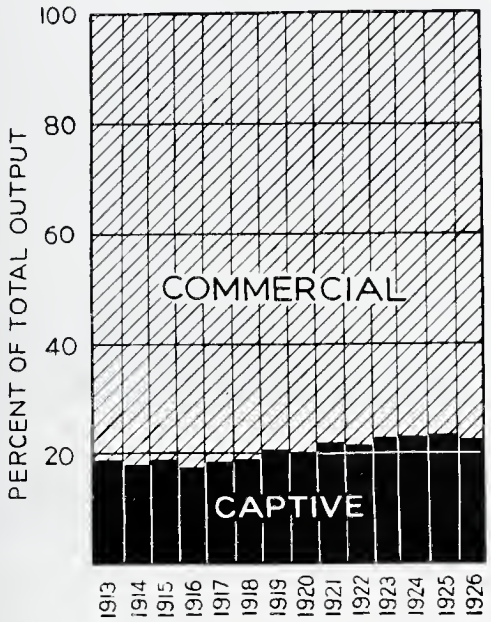

FIG. 11. PER CENT OF THE TOTAL OUTPUT OF BITUMINOUS COAL THAT WAS PRODUCED BY "CAPTIVE" MINES, 1913–1926

"Captive mines" are those owned by consumers, the largest group being the coking-coal mines of steel companies. The high prices of 1916–17, 1920, and 1922 led many consumers to purchase mines, and the captive mines have tended to operate more steadily, particularly in the years since 1920. The percentage of captive coal has therefore increased.

The increase, however, has not been sufficient to change conditions greatly. In 1913 the captive mines produced 18.5 per cent of the total, and in 1926, 22.7 per cent.

capital will be attracted, the prices of pig iron will fall, but the demand for it increase; and eventually the greater number of furnaces will more than make up for the diminished consumption of each. And if such is not always the result within a single branch, it must be remembered that the progress of any branch of manufacture excites a new activity in most other branches. . . . . The whole history of the steam engine is one of economy. In less than one hundred years

. . . . the efficiency of the engine has been increased at least ten-fold. . . . . The reduction of the consumption of coal, per ton of iron, to less than one-third of its former amount, was followed, in Scotland, by a ten-fold total consumption, between the years 1830 and 1863, not to speak of the indirect effect of cheap iron in accelerating other coal-consuming branches of industry. . . . . And if economy in the past has been the main source of our progress and growing consumption of coal the same effect will follow from the same cause in the future."[1]

This prophecy, uttered in 1865, held true for fifty years. Is it not conceivable that it will be found true again, after the present tendency in the coal industry has run its course?

DISCUSSION

MR. E. W. PARKER (Director of the Anthracite Bureau of Information): I should like to ask Mr. Tryon, in regard to that diagram that he showed of the increase in percentage of oil in 1927—the one showing decreases in production of bituminous coal and anthracite—what that oil meant in equivalent of tons of coal.

It would seem as if fuel oil were taking much of the bituminous business. According to the chart oil has increased 169 per cent, so that unless quantities are specified it would appear that the use of coal had fallen off 169 per cent.

What is the equivalent in tons of bituminous coal of the increased production or use of fuel oil?

MR. TRYON: If one takes the total production of crude oil in 1927 and subtracts from that the production of ten years ago, he gets an answer equivalent to 150,000,000 tons of coal.

Everybody knows that much of this exceedingly large increase does not represent actual displacement of coal by oil. Most of it has gone to drive motor cars, and cannot be called direct competition with coal. It is doubtful if even our German friends, with their methods of converting coal into oil, would have been able to take care of the expanding requirements of the United States for motor fuel during this ten year period, if there had not been a vast supply of crude oil.

I think, however, that one can properly feel that gasoline has been an indirect competitor of coal, because undoubtedly had there been no oil, the demand for transportation in other forms would have been greater. Had the need for transportation not been met so well by oil, it would have tended to fall back on bituminous coal.

Studies made by Swanson of the Bureau of Mines now permit comparsion of the present consumption—not of all oil, but of fuel and gas oil with what it was

[1] W. Stanley Jevons, *The Coal Question*, 3d edition, 1906, ed. by Flux, pp. 140–156.

ten years ago, before the present wave of oil competition was felt. They indicate that the great increases in the use of oil that may be said to displace coal are in the bunker trades, in railroad fuel, in heating buildings and in manufacturing, particularly in the refining of crude petroleum. The refining of crude is now one of our very largest manufacturing industries. It is a heat industry and takes an enormous amount of fuel. It consumes today more coal than it formerly did but most of the very large increase in its requirements has naturally been met by the use of crude or fuel oil.

There is much interest in the degree to which fuel oil has taken the place of or supplemented coal in the heating of buildings, and Swanson's study throws light upon that point also. He finds that the total quantity of oil used for keeping people warm, either in their homes or in other buildings, now amounts to about 27,000,000 barrels. Of that, 15,000,000 barrels, equivalent to 4,000,000 tons of coal, is used in commercial structures—large buildings—and 12,000,000 barrels is used in residences, the latter being equivalent to 3,000,000 tons of coal. In making that statement, may I add that this oil does not represent a net displacement of coal, particularly of anthracite. Of course, some of these buildings have been heated with oil for a long time. Others formerly used bituminous coal rather than anthracite. It would be a rash man who would attempt to say exactly how much of this 27,000,000 barrels of oil represents former consumption of anthracite but I suspect that the answer is a million rather than many millions.

MR. NEWELL G. ALFORD (Vice President, Howard N. Eavenson & Associates, Pittsburgh): Based on Mr. Tryon's knowledge of consumption in the past two years, I would like him to tell us what possible effect on coal production there would be from the tendency toward control of oil production and from the increasing quantity of oil that is being sold in the form of gasoline.

MR. TRYON: Mr. Alford's question is decidely out of my bailiwick, and I would be rash if I were to attempt to pass any judgment on the question. I think we can all agree that if the coal people could organize themselves to promote a restriction of crude oil production, it probably would be to their interest.

I think everyone is agreed that there cannot be an indefinite increase over an indefiite period in the quantity of oil available especially that used for fuel purposes.

MR. ALFORD: Do you have reason to believe that there might have been an increase in coal consumption in 1926 and 1927 due to larger quantities of oil being sold in the form of gasoline or perhaps some of those related factors?

MR. TRYON: Apparently the total quantity of oil used for fuel purposes has not changed greatly in the last year or two. Of course, the quantity of gasoline used has increased largely and in that sense coal has been spared from further invasion. I do not perceive there has been any increase in the consumption of coal.

MR. ALFORD: Do you not think the tendency is bound to be in that direction, as the oil man is able to realize more for a gallon of oil sold in the form of gasoline?

MR. TRYON: That again I am not competent to discuss, though I believe the tendency is in that direction.

MR. L. P. ALFORD (Vice President, Ronald Press Company, New York, N.Y.): In one of the early charts the speaker showed a production line of bituminous coal and a straight line, labeled, "normal trend line."

Will you tell us how that was plotted—was it mathematically or just a guess?

MR. TRYON: That normal trend was worked out by Professor E. E. Day in the Harvard School of Business Administration. It was computed for the period of growth up to the World War, including the years 1899 to 1919. On the chart that I showed it was simply projected into the period after the War in order to point out the radical change in the fortunes of coal that the last ten years have brought.

It was computed by a mathematical formula, employing the principle of least squares. This method has been used by Professor Day and by the Harvard School, in calculating normal trend lines for a great number of commodities.

Day's normal trend was a reasonable interpretation up to 1919. It was included in the diagram in order to show what would have happened had the former growth continued. Had this former expectiation been realized, as in fact it was not, we would be consuming today more than we actually are. Day's trend is certainly not an indication of normal for the period since the War. If one were to calculate a similar trend for the period since the War the result would be either a level line or one turning slightly downwards.

SOME IDEAS OF AN INVENTOR ON SCIENTIFIC RESEARCH AND INVENTIONS

By Georges Claude

Paris

One of the things of which I certainly am proud is the cordial welcome which the industry of this great country has granted my inventions. The Air Reduction Company, with fifty million dollars and thirty plants, has given my processes of liquefaction of the air a development worthy of this country. The "Claude Neon Lights" and its fifteen American branches, help to illuminate every part of the United States with the rutilant light of all their neon tubes. Lazote Incorporated, a branch of the E. I. Du Pont De Nemours Company spends fifteen million dollars in its plant at Belle (West Virginia) to bring my hyper-pressure process for synthesis of ammonia to a degree of development unknown even in my own country.

Such a welcome made it my duty to accept the warm invitation of President Baker and to prove my gratitude in coming to your Congress. But what a perplexity! On what should I talk? It is true that a part of my life has been devoted to a question capable of interesting your conference, namely, the treatment of coke oven gas for the purpose of synthesis of ammonia. But after the lecture of M. J. Delorme, everything of interest has been said concerning this matter—and I could not add much to it, especially as I am unable to remain tethered to the same subject, since when an idea of mine has been put into practice, I leave it to my devoted collaborators, and go to another problem. So that synthesis of ammonia is too old a business for me to treat before you now and I should rather speak about the great question which absorbs me at present, extracting energy from the sea, if this matter were not so distant from the object of your meeting.

Then, what was I to do?

Well, I had an idea. A bad one, I am afraid. Taking advantage of the cordial reception in this country on which I congratulated myself a minute ago, I asked Dr. Baker whether you would be interested in being acquainted with some of the ideas that, in my opinion, can give to the inventive faculties their full effectiveness and, then, in finding some justification of these ideas in my own career.

Dr. Baker's answer was that it would interest you. I am afraid he was wrong. The main result, I expect, will probably be to make myself appear conceited by speaking so much of myself. My excuse will be that, not being a politician, I can only speak of what I do know well.

Besides, I have not the least intention of propounding my ideas as new or even excellent. Perhaps some are very open to discussion. Perhaps, they suit only my personal qualities and defects, and would not fit others. I hope, however, they will make you meditate, and my satisfaction will be complete if I can at the same time interest you.

Among these ideas of which I shall speak, one of the most essential is so opposed to the view of many people that I must at once express it.

There are many persons—I think it is the same everywhere—who believe that the more science advances and the more industry progresses, the less remains to be invented. It is just the contrary. Every new resource, every new invention is able to combine with some of the other existing possibilities to permit many other combinations. And I insist: this is not a question of opinion or feeling, it is an absolute, a mathematical certainty; so that contrary to the opinion just mentioned, we ought to believe that our power of realization increases constantly, quickly and indefinitely—and the rapidity of modern progress is nothing other than the confirmation of this fact. Such a positive fact may certainly make us proud of our science. How wrong we should be, however, to forget our dependence upon the admirable variety of the properties of matter and energy. Far from being creators in the sublime sense of the word, we are but the simple utilizers, the simple workmen of these properties. And I need not here remind you that science, rather than boast of knowing the last word of things, feels more strongly every day that the little it knows is little indeed, before the infinite of all that it ignores. The first duty of science and scientists of today, indeed, is to be modest and respectful of everybody's beliefs. Such is the feeling expressed by the great majority of the members of the French Academy of Sciences in a recent inquiry on "Le sentiment religieux et la Science."[1]

But if the first need of an inventor is an absolute and solid confidence in the innumerable resources placed at his disposal by Nature and Science, it does not follow that he can use them without discrim-

[1] Editions Spes. rue Soufflot, Paris.

ination. Getting the result we need from a thing or a substance poorly fitted for that purpose is no longer worthy of science, when it is probable that far better things or substances or combinations can be found to suit that purpose in the immense and ever-growing arsenal of the properties of matter and energy. In that respect, we may venture to say that it is probably heresy for us to do a single thing now as we used to do it a century ago.

It follows from all this that, in my opinion, the difficulty of an inventor is *not* to make an invention, but to choose from among the multitude of inventive ideas which strike his mind *the one* which is surely worth while. This is all the more so as the achievement of a small invention frequently proves to be as difficult as that of a big one.

It follows also that we must never despair because of the difficulties we *inevitably* meet in the study of a problem; for we may be sure that means always exist to overcome these difficulties and to solve the problem.

It follows, further, that for any problem a *simple* solution only is worth considering.

I add, as a personal feeling, that when, in the study of a problem I have to choose between experience and calculation, I prefer experience. "Experience integrates" said my famous countryman, Claude Bernard. I add "Experience forgets nothing in its equations which is not always the case with the most skillful mathematicians." And how true is this saying of Claude Bernard! Many a time an experiment made without any wish of precision, improvised with the poorest means, gives invaluable indications and decides whether some idea is ridiculous or valuable, and I dare say, I have been able in my life to try in that fashion so many ridiculous ideas that I have inevitably met with some good ones.

I spoke about my inclination for subjects of note. It led me to another more questionable conclusion. A rule to which I tie my mind—the best I can, for an inventor's mind is a fiery steed which often leads its master where he would prefer not to go—is to stray from the usual paths, in the simple belief that the less frequented is the way, the greater are the chances of meeting unknown and important things. This, of course, is not invariably true; many times interesting inventions are made in the most explored fields. But the *probability*, of course, of making important discoveries is better in less explored regions.

I agree that this way is not without some serious drawbacks. It

may happen, for instance, that proceeding along a new road you may gain such an advantage as compared to what has been done before, that the result you obtain does not correspond to an existing need, or even appears so fantastic to those engaged in ordinary pursuits that you are kindly advised to take a rest in some lunatic asylum. If you are inclined to find in these friendly remarks excitement and pleasure rather than discouragement, then, all is for the best and this is *my* way.

Now these unexplored regions border generally on the last chapters of science. And that explains why, for instance, as soon as acetylene became industrial, my friend Hess and I took an interest in that new question from whence resulted our invention of dissolved acetylene.

Likewise, as soon as the low temperature became industrial, thanks to Linde's work, I threw myself into that subject, from whence resulted my inventions on liquid air, oxygen and nitrogen.

Liquid air in its turn led me to the domain of rare gases, of which I was the first industrial explorer, and from which neon lighting resulted. It led me also to water and coke oven gas liquefaction and from there to synthesis of ammonia by my personal technique of hyperpressures.

That these different subjects fully satisfied my preferences for important questions is proved by the enumeration I made a moment ago of the capital directly invested in this country in my own inventions which amounts to more than one hundred million dollars. For the whole world, they require a total capital over two hundred million dollars, and I do not include in these figures dissolved acetylene, of which patents are now expired, and of which the sales in the world amount to over twenty million dollars per year.

As to the new question with which I deal today—energy from the sea—if my hopes are justified, it will certainly not yield in importance to any other.

In these different inventions, of course, my confidence in the innumerable resources at our disposal has had many occasions to exert itself. Very often, it has been the only reason for my going into a new question.

Such was the case with the dissolved acetylene industry that I started in 1896 with my friend Hess. The only reason for this invention was our conviction that if we could discover a convenient solvent, by dissolving acetylene in it under pressure, we would procure for its

storing the same advantages as by its liquefaction; moreover, its dilution in an inert liquid, would do away with the terrible explosibility of liquid acetylene which ruined the hopes of the illustrious R. Pictet. Thus we discovered the remarkable solvent properties of *acetone* and its efficiency in removing the explosive properties of acetylene. I remember, as one of my best souvenirs, my joy in examining the Seltzer water siphon filled with a solution of acetylene in acetone under five atmospheres, and in which glittered quietly a thread of platinum reddened by an electric current. Note that in spite of my confidence in the result, it was from some hundred yards and through an opera glass that I enjoyed that sight.

I take pleasure in noticing that in spite of immense quantities of dissolved acetylene now manufactured, the formula we gave twenty-two years ago, is always used; and the liquid used is always the one we chose among thousands and thousands, namely, acetone.

It was the same confidence in our resources which led me to the liquid air industry.

You know that practically the only source of cold used to bring air to liquefaction is the expansion of compressed air. But we can expand it *without external work*, that is by a simple tap, or *with external work*, by causing compressed air to move a motor. This second method is of course better, since it allows us to remove more energy from expanding air, thus cooling it more. Why, then, did Linde prefer the first method? Well, because the expansion machine cooling excessively, the lubricant used will freeze and block the machine: "One cannot therefore," affirms Linde, "reach such a result by such a method."

At the reading of the Linde pamphlet—I will arrange to give in two lines the very simple story of an invention—I started. "How is that?" I asked myself, "The lubricant will freeze? If it is freezable, yes; but if it is not, it will not freeze, I suppose! And the machine will turn." And on only this rather elementary remark, moved by this hope, I undertook to find out among all the liquids of chemistry the one which would suit my purpose. Soon petroleum ether revealed to me its properties, and the machine worked, and of the supposed insurmountable obstacle which stopped Linde, nothing, absolutely nothing remained for me.

Now, we may almost affirm that it is always the same; conclusion: when a thing is theoretically possible, when only practical difficulties prevent it from being achieved, we may be assured that these

difficulties are not insurmountable; and that at the cost of more or less time, of more or less labor, an artifice will be found to solve the difficulties and to give satisfaction to theory.

It is amusing that petroleum ether itself is, in fact, useless for the operation of liquid air machines as I soon discovered. So energetic is the effect of the expansion that the cooling is very quick, and after a few minutes the liquid air itself produced in the machine is all that is needed for its lubrication. So that the bar which so completely stopped Linde in that way was in reality but a shadow and that petroleum ether was only for me the opportunity to bring my effort to this marvelous question.

Besides, it is curious to notice the important rôle played by these questions of lubrication in my career. Another example occurred in 1916 when Germany opened the war of gases against the French. During some days, you remember, it was believed that all was lost and that under the waves of chlorine our lines would be carried away. It was a question of life or death to answer the attack. Unfortunately, neither in England nor in France, did we know how to liquefy the indispensable chlorine. This gas, however, is one of those that liquefies at a very moderate pressure, but the difficulty came from the virulence with which *wet* chlorine attacks metals. It is not possible, therefore, to liquefy chlorine with ordinary compressors, which, furthermore, it would not be possible to lubricate, owing to the fact that oils and greases are likewise destroyed by chlorine. Such was at least the belief of chemists, and you will agree it appeared very sensible. Before the war, however, I had to consider the question and one day an idea jumped into my brain, as often happens. I knew that *dry* chlorine does not attack metals. I knew that concentrated sulphuric acid does not attack them either. I knew that sulphuric acid, in addition to its drying properties, possesses lubricating qualities which is fully attested by its old name of vitriol oil. I knew, finally, that *this* oil is not attacked by chlorine. Putting this and that together, the idea came to me to liquefy chlorine in ordinary compressors lubricated by sulphuric acid which would at the same time oil the compressor and maintain the perfect dryness of chlorine. I had abandoned the idea because of lack of time and suddenly, circumstances gave to the success or failure of this idea a tragic interest. I made the test; the test succeeded. From that minute, liquefying chlorine became as easy as liquefying sulphurous acid and soon, tons and tons of liquefied chlorine came to the

help of our soldiers. And, I repeat, that is always the same. Find out in every case, among the innumerable properties of matter, the only one really fitted to the difficulty, apply it, odd as it may be, and the difficulty fades away.

Another time, engaged on the occasion of synthesis of ammonia in the extraction of hydrogen from mixtures like water gas, I had difficulties with the machine in which the gaseous hydrogen which subsists after condensation of carbon monoxide produces by its expansion the cold required for that condensation. When the temperature was not too low to allow a certain amount of CO to reach the machine, and to liquefy in it, this liquid CO *lubricated it;* but if the temperature went down to −206°C., CO froze and blocked the machine. Now, more than −206°C. is necessary to get pure hydrogen, so that I was very much worried until the day I thought of injecting into the machine a certain amount of *liquid nitrogen,* which would not spoil hydrogen since this hydrogen was to be mixed with nitrogen to make ammonia; and the said nitrogen, which freezes only at −211°C. would lubricate the machine and assure the very low temperature required to get pure hydrogen. I tried: as soon as nitrogen arrived, the machine accelerated cheerfully, the temperature decreased and pure hydrogen was soon obtained. Now, my compressors of chlorine oiled by sulphuric acid and my hydrogen expansion machine oiled by nitrogen, are two choice pieces in my collection of strange apparatus.

Here is another example of this belief *a priori* in properties of matter:

Perhaps you know that for thermodynamic reasons I proposed for the synthesis of ammonia the use of pressures, exceeding by 400 per cent all those used before by any industry, and which I named hyperpressures. If I did not succumb in this occasion under the criticisms of those who never fail to talk of difficulties without considering that an engineer deserving the name knows difficulties only to subdue them; if I did not succumb, I say, it was certainly due to my obstinacy—the main quality for an inventor, I dare say.

Some of my critics objected to the high energy needed to compress the gases to such a pressure, without noticing that the work of compression, increasing only as the logarithm of the pressure, is, at 1000 atmospheres used in my process, only 30 per cent higher than at 200 atmospheres of the Haber's process. Others objected to the tightness of the apparatus, already so difficult to maintain at 200 atmospheres.

They assumed it impossible at 1000 atmospheres. To this I replied, apparently paradoxically, that difficulties in tightness came rather *from the size of the joints*, than *from the pressure itself*, so that the use of hyperpressures, which greatly reduce the sizes of the apparatus, would rather be easier than the use of ordinary pressures, and this proved to be true.

Other critics doubted as to the behavior of my future catalyst tubes under the enormous combined effects of such pressures and of temperatures of about 600°C. To this I answered that metallurgy, already producing metals resisting 400°C., would certainly be able to extend the limit 200° further when necessity would demand. Then, so true was this, that, having occasion at that time to examine the remarkable metal B.T.G. devised by the Commentry-Fourchambault Company and M. Chevenard for the difficult conditions of gas turbines, I soon recognized in it the metal I dreamed of.

The success of these ideas, of course, caused my most determined opponents to change their minds. They denied everything. Now, as usual, they declare everything as evident.

We touch here one of the more sensitive points of an inventor's life, chiefly when not successful. When his thoughts and his efforts have resulted in a very useful but very simple device, as often happens, then his days of doubt, his days of suffering when he struggled in the dark, are forgotten by those who have interest in doing so. They consider the results of his labor evident and too often courts share this opinion. Allow me, gentlemen, as a man who many times found himself in this darkness, to protest against this, in defense not only of my own interests, but above all, of the interests of the thousands of inventors so rarely rewarded by success.

That is why I was particularly pleased by the recent decision of the Court of Appeals of New York, sustaining my six years of hard work on neon lighting which the newcomers in this field, on the ground of the present simplicity of my devices, had claimed to be valueless. I feel strongly that this decision of the New York Court of Appeals is right and that it is right in most cases. I think that, during the short privilege granted to them, inventors, so useful to human progress but so exposed to disillusion and bitterness, must be protected against imitators, against infringers, and for that purpose judges, in order to judge soundly must make an effort to put themselves in the place of these inventors when they struggled, and doubted, and despaired in the dark.

In the field of hyperpressures, as in that of neon lighting, of course, after the objectors came the imitators, of whom the most successful was Dr. Casale. This prominent engineer, following my technique in using hyperpressures and extracting the heat of reaction from the catalyst tubes—and liberated by my own experience from all my stumbling blocks—succeeded in avoiding the use of special metal in the catalyst batteries.

I told you how my confidence in the properties of matter led me to the liquid air industry and to the transformation of it by the use of expansion machines. You know that the most important use of the liquefaction of air is to allow us to separate this air into its elements, in order to get pure oxygen and pure nitrogen, both very useful in many industries. I should like now to show how all my improvements in this second matter were based purely on a question of common sense. Common sense is in fact always the best guide.

About 1900, however, common sense had strangely failed in the minds of those who were then interested in this question.

Though these scientists all agreed that when liquid air *evaporates*, nitrogen being more volatile escapes chiefly in the first portions, while oxygen concentrates more and more in the remaining liquid, on the inverse question, *condensing* of gaseous air, their opinions were far from coinciding. While Sir W. Ramsay admitted that in such a condensation oxygen condenses *first*, according to the other great English scientist Sir J. Dewar, oxygen and nitrogen liquefy *together* during the progressive liquefaction of the air in the invariable ratio which constitutes atmospheric air. On the contrary the celebrated Raoul Pictet assumed that *nitrogen condenses first*, so that, very strange phenomenon indeed, the Pictet's nitrogen was *more* volatile than oxygen in vaporizing but *less* volatile in condensing. But if Pictet's statement was evidently absurd, Dewar's appeared to me nearly as contrary to good sense. Liquid oxygen remaining last when liquid air evaporated, one does not see why, in the inverse phenomenon, it would not condense by preference in the first portion, according to Ramsay's suggestion. I know that such errors of judgment of very eminent people were very excusable: in these unknown regions of terrific temperatures, everything looked so different in the eyes of the first explorers that they could feel as in a new world in which usual reasoning was no longer possible. My only merit in that question was to realize a little sooner than the others that as I said, here as everywhere, common sense never loses its rights.

At any rate, according to my habit, a small apparatus was built to cause gaseous air to condense partially and methodically, and soon I had the satisfaction of getting a liquid with a much larger proportion of oxygen than air.

Now the fact so ascertained was of very great interest. If Dewar were right that no separating effect occurred during liquefaction of air, we had to rely *only* on the subsequent evaporation to separate oxygen and nitrogen, and this was what Linde did on the strength of Dewar's statement. If I were right, if some separating effect did occur during condensation, then, both particularities of condensation *and* evaporation would be utilizable and the result far better. Such have been indeed the consequences of this simple question of common sense. It allowed me, by using what I called the *backward return*, to separate the air, during its condensation, into a liquid of high oxygen grade, and into liquid nitrogen, and these two liquids, used according to my now classic *double rectification process* permitted me the complete separation of air into pure oxygen and pure nitrogen.

Do I need, gentlemen, to remind you of the considerable growth achieved by this industry of liquid air, despite the many people who mocked Professor Linde and myself at our start. Today, thousands of machines work throughout the world, the most powerful of them treating 2,500,000 cubic feet of air every day. Such is the efficiency of these large machines of today that air compressed to less than 10 atmospheres find in itself by this single operation all it needs to dry, to cool, to liquefy, to evaporate and to return to the gaseous state separated into its elements with such a perfection that the purity of oxygen exceeds 99.6 per cent and nitrogen contains less than 0.1 per cent of oxygen.

So, the development of this industry fully justified my hopes, though in one way entirely unforseen by me at my starting. That is the welding and cutting of metals, this remarkable method of cutting like butter pieces of iron 2 feet thick even when immersed thirty feet *under water*.

On the other hand, metallurgy and chemistry, which I should have thought would have been the first to use cheap oxygen have used it but very little. But now, the liquid air industry is fully ready for such a development and I do not doubt that American industry will not be the last to enter this field, which our experiments in blast furnaces at Ougree, Belgium, previous to the war, already showed to be of such great interest.

Now, then, you know that air is no longer the simple mixture of oxygen and nitrogen our fathers supposed. The wonderful work of Ramsay showed it to contain the most extraordinary collection of strange gases, that is rare gases. Confident that some day their remarkable properties would assure them important applications, I planned to putting them at the disposal of science and industry. For that purpose, instead of getting these gases by the extremely expensive treatment of air specially for this purpose, I devoted my efforts to obtaining them as by-products, and therefore at a low cost, during the normal operation of the large industrial oxygen apparatus.

The first two rare gases I obtained that way were neon and helium. Contrary to Sir W. Ramsay, who got them in the first portions of evaporation of liquid air, I sought and found them in the unliquefied residue of the progressive and methodic liquefaction of air.

Now, the extraordinary electric properties of neon makes it a very interesting substance. It produces light, I dare say, as birds sing.

According to my idea that the specific properties which certain substances possess to an exceptional degree are our most powerful resources in solving problems, I engaged myself in 1907 in the question of neon lighting. As early as 1911, such were the results of my work that I did not hesitate to buy my patents from my Societé l'Air Liquide to which they belonged, and this company only began to realize the importance of the question on account of the high price I agreed to pay.

But it happens, as I said before, that too new a question often pays for its novelty by having no existing need. And, this time, my hopes narrowly missed failing and the starting of neon lighting was very difficult. It is curious to notice that it was in this very town, at the convention of the Illuminating Society of 1913, fifteen years ago, that I myself presented for the first time in America my neon tubes.

The tubes I showed on this occasion were exactly like the present tubes as to their shape, their sizes, the intensity of their light. However, I could not succeed in arousing interest in them. Some days later, at the convention held by the Directors of the American Edison Societies, in Cooperstown, I gave a second lecture with the same lack of success. I suppose that my English, which was then rather worse than now, which is saying much, was somewhat responsible for this. At any rate, it proved that it is not always an advantage to be too much ahead of one's time.

Soon after came the war—and this matter of neon lighting had to

sleep until recent years before finding its way into America, thanks to the efforts of my friend Hollingsworth, promoter of all my inventions in this country and president of the Claude Neon Lights of New York, and thanks to the able defense of my patents held by MM. Prindle, Ewing and Bohleber before the Court of Appeals of New York, with the result which I have mentioned above.

Among the other rare gases of air, Argon is furnished in appreciable quantities to-day from oxygen apparatus. As you know, it is used in incandescent lamps with inert atmosphere, which so curiously upset all the technical and practical conditions of incandescent lighting.

Krypton and Xenon have been much more difficult to get, owing to their minute ratio in air, which does not exceed one part out of one million for Krypton and of ten millions for Xenon so that the English optician Hilger charges $15 per cubic centimeter of Xenon, $3,000 a gram, almost as expensive as radium. Two months ago, however, I was able to inform the Academy of Sciences of Paris that, after fifteen years of effort, I had at last succeeded in extracting these gases in good quantities and, according to my program, in a continuous operation from one of my oxygen apparatuses. My process already gets 40 per cent of the total amount of Krypton and Xenon contained in the air which passes through the apparatus. This apparatus treats 25,000 cubic feet of air per hour, so I am in a position to obtain 1 liter of Xenon per day. The result is important, as Xenon and Krypton being extremely curious gases, will not fail to find interesting uses; all the more so that, as I remarked, dissolved gases of water, which our future plants of energy from the sea will liberate in immense quantities, probably contains 5 times more Xenon and Krypton than atmospheric air and will be able to give them in large quantities.

This technic of liquefaction of air is so fertile that I soon thought it worthy to be extended to other gases. As early as 1903, I studied its application to extracting hydrogen from gaseous mixtures—which is another example of a simple application of the properties of matter; expansion of the *compressed* mixture produces cold, as usual: hydrogen, very refractory to liquefaction, remains gaseous while all other components are either liquefied or solidified. Nothing could be simpler as you see, at least in theory.

When I started these studies in 1903, hydrogen had few or no applications, but suddenly it acquired enormous importance owing to the work of Nernst and Haber on synthesis of ammonia.

You know that it was because of its advance in this respect at the beginning of the war that Germany withstood so long the efforts of the Allies; no example is more poignant of the formidable power of science than the example of this miserable reaction of the laboratory so long unable to produce even a trace of ammonia and then suddenly acquiring such an importance that it came within a hair's breadth of changing the fortune of the war.

The war ended, I realized the extreme importance for my country to contest the Germans the nitrogen monopoly, the value of which has not decreased since the war, as nitrogen yields fertilizers as well as explosives. The task demanded more than imitation. I had to take into careful account the respective conditions of German and French industries at the end of the war.

First, I had to adapt synthesis of ammonia to French conditions. If German technic in that way has been so successful, it is because of the extraordinary magnitude of views and means of its eminent engineers. All the people who, after the war had the chance to visit the Badische plant of Oppau, remember the crushing effect of these immense factories, of these monstrous apparatuses, triumphs of German engineering, in which pressures never used before combined their action with that of temperatures neighboring upon the red hot.

But at the end of the war, French industry, practically crushed, was entirely incapable of the gigantic and magnificent effort of Germany at war. I had to find another way. I just told you how I achieved my aim by means of these hyperpressures which, by excessive reduction in size, by the great increase of the factor of combination, enabled me to devise plants easily realizable in France as soon as I solved the essential problem of removing from the batteries the heat of reaction.

Then, I had to adapt to French conditions, the manufacture of hydrogen. Germany gets hydrogen at great expense from coal, from lignite of which she has plenty. On the contrary, France is poor in coal. She needs something else. In 1920, I showed that the solution is in using the torrents of *coke oven gases* in order to extract by a convenient process the 50 per cent hydrogen they contain. I applied to these gases my liquefaction process for hydrogenol gases of 1903, which I just described, taking into account the difficulties resulting from the complexity of this gas and of its numerous compounds. This conception is, I dare say, a very logical one. While the only value of those coke oven gases is their calorific value, the calorific value of hydrogen

in volume, is as you know, negligible, 3000 as compared to 10,000 for methane. It is therefore very logical to remove this hydrogen from those gases and transform this bad fuel into a valuable chemical, that is, ammonia, while the other constituents go back to the coke oven for calorific purposes. At the same time, were cover all the benzene, all the ethylene, etc., from those gases as is easy to do in a liquefying process. All at once, the plant is thus liberated of all the costly features of the Badische system for the production of the gaseous mixture to be treated.

This process of manufacture of hydrogen from coke oven gas is now proven by practice, just as it is proven for the technic of hyperpressures. All the large plants which use my process in France, Belgium, Czecho-Slovakia, etc., are increasing their output—and necessity has led to the installation of more and more important units to meet the large increase in consumption of nitrogen, which is among the most essential requirements of today.

This necessity led us to build catalyst batteries of large output with ordinary steel tubes. We have now such units with capacities of 25 tons anhydrous ammonia a day. It led us, also, to more and more powerful hydrogen apparatus. Our last type is able to treat 6 million cubic feet per day—however small are its sizes.

In view of such results, I regret that special conditions of American industry prevented the distinguished staff of Lazote Incorporated from obtaining hydrogen by this process.

I remain confident, however, that it is the process of the future, and that here as elsewhere, it will be adopted when nitrogen has attained the place it deserves.

I now approach the end of this too long lecture with a few words about my last preoccupation, the development of thermic energy from the sea. I need not tell you that for modern humanity cheap energy is a question of life or death. Without energy, nothing can be done, and as you know, engineering, in one of its most important features, is a perpetual struggle to save this energy by better and better efficiency. Nevertheless, our consumption of energy increases alarmingly and in spite of a recourse every day more intense to hydraulic forces, our precious resources of coal and petrol will certainly not last more than a few centuries. Therefore, it is time to think about other sources to replace them. This would be easier if these new sources could possibly give energy at lower price than the *present ones;* in other words, if they could be of interest not only for our heirs, but for ourselves from the present time.

Such is the result which M. Boucherot and myself believe possible.

Most of the people who have thought about the question have concluded that among unemployed sources of energy of today, only solar heat is worth while. Accordingly to Hirn the solar radiation falling on our earth is theoretically not less than sixteen hundred thousand horse power per square mile. Allow only a 1 per cent efficiency utilization process and look at the result! But, how to utilize this energy with the necessary regularity and continuity, in spite of clouds and nights, is a problem even in tropical regions. To answer these questions and see how it would be possible to obtain motive steam by means of the sun, I went to the Sahara in 1924. I soon perceived that even in these torrid regions, one could not hope to get steam under pressure, in the common sense of the word, that is, under an absolute pressure surpassing 1 atmosphere, corresponding to water boiling at 100°C. However, you know that water easily boils at any temperature below 100° in a boiler *deprived of air* and from which steam is continually removed in proportion to its production, thanks to the suction of a condenser in which this steam is condensed by *colder water*. Now, this steam, so produced under 1 atmosphere, can very well run a turbine on its way to the condenser. All this is well known and industrially used, with motive steam at no more than 0.8 and 0.7 atmosphere, but I have been led to extend this possibility far below what was supposed possible.

During my stay in the Sahara, in fact, a happy misfortune sent me rain rather than sun. This caused me to think that, even in these countries it would be wise not to rely upon boiling temperatures above 60° or 70°. So, little by little, I accustomed myself to the idea of using steam at lower and lower absolute pressure. And, when thinking one day of the remarkable fact that deep sea temperature is everywhere, even in the tropics, near the freezing point, while the tropical sea surface water remains uniformly above 25°C., an idea occurred to me that I should have considered foolish had it not been for this progressive training. The idea was that such temperatures as 25°C. and 4°C. would be sufficient to produce steam, to condense it, and move turbines and this 24 hours a day and from the beginning to the end of the year!

Appearances, however, were not encouraging.

At the temperature of 25°C., the pressure of the steam furnished by the boiling is only 0.03 atmosphere. On the other hand, the vacuum maintained by the cold water is 0.01 atmosphere. Thus,

the acting difference of pressures between boiler and condenser will not exceed 0.02 atmosphere, or only $\frac{1}{750}$ that of industrial steam at 15 atmospheres. What could be expected from such conditions?

However, the Carnot formula showing my hope supported $\frac{25-5}{300} = 6.6$ per cent to be the efficiency of a cycle performed in such conditions, which is not ridiculous at all in comparison with the 15 to 20 per cent in ordinary steam machines. The Carnot formula was true. I soon understood the reason. So small is this difference of pressures of 0.02 atmosphere it is able to move the steam flowing from boiler to condenser at the unexpected speed of 500 meters per second, because, in the well-known formula $V = \sqrt{2gh}$, the difference of pressures h must be expressed in the height of a column of the acting fluid, which is here infinitely slight, since it weighs only 25 grams per cubic meter. So the speed of this rather immaterial steam is not very much below that of ordinary steam, which does not exceed 1500 meters per second; and such a steam is capable of moving the simplest of all turbines, the single expansion one, at the especially favorable speed of 250 meters per second. Moreover, I was led to a greater satisfaction yet in perceiving that theoretically this immaterial steam would produce the same work as would the surface water producing this steam in falling 300 feet. While the best tide utilization corresponds to a 12-foot fall!

I informed my friend Boucherot of these results.

Hurrying to control these amazing inferences by experience, we devised a small turbine with the help of my young cousin, Andre Claude, then plunged it into the steam current flowing from a balloon containing water at 30°C., to another balloon filled with pieces of ice to condense the vapor—and, to our joy, the turbine ran at full speed.

We elaborated, then, our plan of harnessing the ocean, if I dare say so. The test was repeated with great success, first before the French Academy of Sciences, then in America, Canada and Cuba. The technical conditions of Cuba, in fact, caused us to believe that there will be the place of our first industrial plant.

Once more then arose the song of those who, rather than acting themselves, prefer criticizing others. All the more disagreeable were these criticisms since most of them came from eminent specialists, who went as far as to deny me the right to address the public about such

an imposture! Some of them argued that so small would be the work of the turbine, so important its losses by friction that it would not start. And however, I could answer like Galileo, "And yet it moves."

Yes, retorted competent critics, but you manage in your tests not to have dissolved gases, and dissolved gases that is the question! To extract them, according to our calculations based on the practice of steam turbines, you will spend 400 per cent of the energy of the turbine. Now, to appreciate how impassioned objectors may make fools of themselves, let us say that those terrific losses amount not to 400 per cent but to 7 per cent!

Some others questioned the tightness of the apparatus for such a vacuum. Others asserted that cold water from the depth would arrive entirely heated at the surface, etc. In short, it was a complete smashing of our proposals, for in spite of the past of both Boucherot and I, they were very rare, those who, like your *Scientific American*, admitted that if this proposal could startle engineers, our past ought to make them give us credit.

Such indeed was this opposition—so true is it that objectors are too often the wreckers of progress, that I stopped all my efforts to constitute a company, and decided not to go ahead before having proven our ideas at my own expense. This proof, you know, was given at Ougree in Belgium, thanks to the help of the powerful metallurgical firm of Ougree-Marihaye where a turbine of 60 kilowatts was successfully moved at 6,000 revolutions per minute by the action of a difference of temperatures of 18°C. I have now but to prove that the difficulties of the installation of the sea are equally soluble. For that purpose, I plan to have my Ougree plant transported to Cuba, where these ideas have met with the best welcome, and to connect this plant with the deep waters by a convenient pipe as soon as I have ascertained the submarine current, temperatures and depth conditions in the vicinity of Havana, which I am now doing.

After that I shall probably be in measure to pass to the realization of the first of our industrial plants, which shall be a 12,000 kilowatt one.

Ladies and gentlemen, I am at the end of this too long lecture. You see plainly now by all I have said that the greatest difficulties for an inventor come chiefly not from matter but from man, and that in consequence the quality which in my opinion stands by far at the highest place among all those necessary in that hard profession of invention, is *character*.

THE PART OF THE CATALYST IN THE PROCESSING OF COAL

By Hugh S. Taylor

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The attention which has been devoted, during the present meeting, to the practical, industrial and economic factors in the utilization of coal, in a variety of addresses, suggests that, in the present contribution, some of the chemical principles which underlie these factors may advantageously be considered. All processes for the utilization of coal are, in the last analysis, based upon the chemical reactions to which coal may be subjected. The direct burning of coal, now generally recognized as, in many respects, a wasteful process, involves the oxidation of carbonaceous and hydrocarbon material, the reactions supplying heat energy, which may then be utilized in manifold ways. When, however, coal is first subjected to some form of treatment before the process of combustion is attempted, a variety of other chemical reactions may intervene, the objective of which is to increase the value of the products obtained or to bring the carbon and hydrogen content of the coal into some form in which its application is more convenient. These reactions are only in part oxidative. They may also involve both processes of polymerization and depolymerization, hydrogenation and dehydrogenation, dehydration and interaction with steam. The feasibility of such initial treatment from the economic standpoint is determined by two sets of factors, the efficiency and the cost of the pre-treatment on the one hand and the value of the principal and by-products of the operation.

Modern chemical technology has benefited largely in increased efficiency and economy of its operations by the utilization of catalytic materials to accelerate the rate of a wide variety of chemical reactions. One need only recall the contact sulphuric acid process, and the synthesis of ammonia under elevated pressures, to realize how greatly the chemical industry of 1928 differs from that of the preceding century and how far this is a function of the utilization of catalytic materials. Much of this progress has been of an empirical nature; but, from the accumulation of experimental material, there has been obtained a body of general principles which serve as guide in a more direct attack upon newer problems. It has emerged that,

for a given type of chemical reaction, catalytic materials of a given type or types are especially suitable, and that a catalyst for one type of reactions is generally not suitable for another class of process. Thus, for hydrogenation processes, metallic catalysts, of a quite restricted range, have, in general, found application. It has been known, however, for a long time, that a certain group of difficultly reducible oxides, had dehydrogenating activity and this observation has recently been turned to successful commercial use in the reverse operation, the hydrogenation of carbon monoxide to methanol. In this synthesis, the more active hydrogenation agents, the metals, have not proved successful, owing to their ability to reduce the carbon monoxide completely to methane or to effect its decomposition to carbon dioxide and carbon. The experience gained with these oxide catalysts, also, has shown them to have a structure more resistant to destruction by heat and less sensitive to poisoning by impurities in the reactants, notably sulphur compounds, water and oxidation agents generally. It is this feature of oxide hydrogenation catalysts which makes them of especial importance in problems involving the use of hydrogenation catalysts in fuel utilization—problems in the solution of which the metal hydrogenation catalysts will play a minor rôle.

That these conclusions from general experience in the catalytic field are in harmony with developments in fuel technology is evident from a perusal of a large body of patent literature relative to the production of liquid products from coal which has appeared in the recent past. There is, in this literature, a conspicuous absence of the usual metallic hydrogenation catalysts whereas such oxidic agents as molybdenum, tungsten, chromium oxides with alumina, magnesia, zinc oxide and potassium carbonate as promoting agents find frequent mention. It may quite freely be predicted that the use of the metallic hydrogenation catalysts will in general be of little avail in such operations as the hydrogenation of such complex substances as coal where, simultaneously with the hydrocarbon material, there are present impurities which have a very deleterious, poisoning action on these highly active but sensitive catalysts. For catalytic acceleration of hydrogenation in the presence of sulphidic poisons one is therefore forced to look towards the oxide catalysts.

For catalyzed reactions involving dehydration and hydration, another group of oxide catalysts, as well as the alkalies and alkaline earths, are of first importance. Such oxides as thoria, alumina, tungstic oxide, silica, titania and zirconia are, par excellence, catalysts

of dehydration or hydration in contrast to the oxides of zinc, magnesium, manganese, vanadium and molybdenum which are the more important of the group of hydrogenation oxide catalysts already discussed. Chromium oxide varies in its behavior between the two reactions. It is a useful promoter of the hydrogenation reactions of zinc oxide, but in other modes of preparation it has a definite value as a dehydration catalyst or as a promoter of interactions of materials with steam. The importance that the alkalies may have in such dehydration reactions is well illustrated in commercial practice by the change produced in the methanol synthesis by the addition of alkalies to the normal methanol catalysts. The presence of alkali, even in minute quantity changes the product from an almost pure methanol to one in which increasing quantities of higher alcohols are present. The rôle of alkalis as catalysts of hydrolysis and dehydration in liquid systems is part of the everyday technique of the organic chemist. Acids both dilute and concentrated perform a similar work and they are not without importance in fuel technology since the hydration of unsaturated hydrocarbons to yield alcohols and the esterification of these latter are among the illustrations of acids as catalysts of hydration and dehydration.

For oxidation processes, the metals of the platinum series, as well as oxides and salts of metals which can exist in two or more states of oxidation are the most important catalytic materials. Such catalysts are of material use in the by-paths of fuel technology. Platinum, as the contact agent in sulphuric acid manufacture and in the oxidation of ammonia, is an important agent to all large scale consumers of fuel who wish to evaluate to the maximum the sulphur and nitrogen contents of the fuel. The recent commercial development of vanadium oxide catalyst for the manufacture of sulphuric acid supplies another example of the generally robust nature of the oxide catalyst as opposed to a metal catalyst, and of the relative insensitivity of such masses to poisons, notably, in this case, arsenic oxide and sulphur trioxide mists. In the evaluation of tars, notably in the naphthalene, anthracene, benzene and toluene constituents, the part of the oxide catalyst having several stages of oxidation, and principally vanadium, molybdenum and tungsten oxides, is also well known.

The classes of chemical reactions which may be grouped generically under the titles of polymerization and depolymerization and which may be of paramount importance in all classes of coal processing which involve carbonization and distillation have not attained to so

systematized a study at the hands of the catalytic chemist as have those reactions discussed in the preceding sections. There is abundant evidence, however, in the catalytic literature, that such processes are susceptible to acceleration by the judicious use of catalytic materials. By way of illustration may be cited the agents used in the polymerization of hydrocarbons, processes which must be involved in the carbonization industries. In addition to acids, which would normally be of use in aqueous liquid media, such materials as zinc and aluminium chlorides, stannic and antimony chlorides, peroxides, alkalies, alkali metals, alkali sulphides and sulphur have all been invoked for polymerization processes.

That such agents may be of commanding importance in the carbonization industries is at any rate suggested by numerous isolated observations in the fuel literature. Two such may be cited. In the discussion which succeeded the contribution of Dr. F. Bergius to the First Conference on Bituminous Coal in Pittsburgh it was brought out that the addition of iron oxide to the coal-oil mixtures subjected to the high pressure hydrogenation process was not for the purpose of utilizing any catalytic efficiency that the iron oxide might possess. On the contrary, Dr. Bergius stated that it had been found "that the presence of sulphur in coal, coal products or oils may cause polymerization and that means coke formation. Such polymerization product is always formed at a higher temperature. We have found that by adding a little iron oxide it practically avoids such danger. Our opinion," he adds, "is that it has the effect of taking away some special form of sulphur which endangers the reaction and which makes the coke formation easier."

What is found in the high-pressure hydrogenation of coal may also be true in the much more extensive industry of coal carbonization. That such is the case is very definitely indicated by some remarks of Professor J. W. Cobb, in a discussion of the "Utilization of Our Coal Supplies" at the Leeds meeting of the British Association in 1927.[1] Professor Cobb points out that "if one considers such oxide constituents as commonly occur in the ash of coal, alumina and silica which usually occur in the greatest quantity, these have little or no effect, but lime, oxide of iron and soda materially influence the process of carbonization. This is very apparent on the laboratory scale, where much finer grained, stronger and more homogeneous cokes have

[1] Chemistry and Industry, *46*, 845R (1927).

been produced by the addition of five per cent of these materials. The full explanation," he adds, "is not forthcoming, but it would appear that the evolution of volatile matter during the plastic stage is slowed down, and the puffing-out and honeycombing of the coke lessened on that account. On the larger scale, these special cokes are, however, not obviously different in structure from pure coke made without additions, presumably because the (large scale) process is in any case so much slowed down that the differences are smoothed out. It is likely that in processes of rapid carbonization on any scale they will be retained."

Professor Cobb further points out that "there are some interesting points in the larger scale results. Thus, the gas yield was increased 20 per cent with a sodium carbonate coke, and the ammonia yield by 35 per cent with a calcium carbonate coke. But, what is of greatest importance from our present standpoint, is the interesting change which has been brought about, on either the laboratory or the large scale, in the properties of the coke by these additions. On gasification in steam, the laboratory equivalent of the water-gas process, the cokes made with alumina and silica additions behaved exactly like pure coke, but the cokes made with lime, oxide of iron and particularly sodium carbonate, behaved quite differently. They gasified more quickly and gave a much better water-gas."

Table I from Professor Cobb's paper shows abundantly what the changes were. "The reactivity of the coke to steam was so far enhanced by the additions, that the rate of working could be increased tenfold, or more, without impairing the quality of the gas made. These results were obtained at 1,000°C. At lower temperatures the influence of the added constituent was, in some ways, even more remarkable. . . . . Perhaps one of the most striking examples was obtained by the comparison of the behavior, at 800°C., of a pure coke and a sodium carbonate coke, with the steam supply at 10 liters per hour to 10 grams of coke. With pure coke 0.9 gram of coke was gasified per hour, yielding a gas containing 18 per cent of carbon dioxide. With the sodium carbonate coke, 5.8 grams were gasified per hour and the gas made contained only 1.7 per cent of carbon dioxide, which represents six times the rate of gasification with only one-tenth as much carbon dioxide in the gas. This enhanced reactivity of coke towards steam is obviously of direct importance for the making of water gas and the steaming of coke in gas retorts and also in nearly all gas-producer practice where coal and coke are

gasified in air and steam." Professor Cobb established likewise the efficiency of reduction of carbon dioxide at 1,000°C. by cokes containing these reagents.

These results of Cobb supplement and confirm some earlier work by Taylor and Neville[2] on the interaction of steam and carbon dioxide with various types of carbon, the temperature of investigation, in this case lower, being from 490° to 570°C. In our work it was shown that sodium and potassium carbonates were the most efficient accelerating agents for both reactions. Five per cent potassium

TABLE 1

GASIFICATION OF SPECIAL COKES IN STEAM AND CARBON DIOXIDE

COKE USED 10 GRAM SAMPLES	GAS ENTERING	RATE	RATE OF COKE GASIFICATION	CO_2 IN GAS LEAVING	CO IN GAS LEAVING	TEMPERATURE OF FUEL
		liters per hour	*grams per hour*	*per cent*	*per cent*	*°C.*
"Pure"	Steam	2.5	1.15	5.2		1,000
5 per cent Fe_2O_3	Steam	21.9	10.5	5.0		1,000
5 per cent CaO	Steam	11.2	5.2	5.4		1,000
5 per cent Na_2CO_3	Steam	21.0	—	0.4		1,000
"Pure"	Steam	10.0	0.9	18.0		800
5 per cent Na_2CO_3	Steam	10.0	5.8	1.7		800
"Pure"	CO_2	6	—	—	47.8	1,000
5 per cent Fe_2O_3	CO_2	6	—	—	93.0	1,000
CaO	CO_2	6	—	—	95.0	1,000
Na_2CO_3	CO_2	6	—	—	97.0	1,000
"Pure"	CO_2	6	—	—	14.0	900
5 per cent Fe_2O_3	CO_2	6	—	—	70.0	900
5 per cent CaO	CO_2	6	—	—	63.0	900
5 per cent Na_2CO_3	CO_2	6	—	—	82.0	900

carbonate accelerated the reaction with steam ninefold at 570°. Sodium carbonate was less efficient. Our experiments also indicated that the accelerating influence was the more marked the lower the operating temperature. This is true also of the work of Cobb. There is, however, one outstanding divergence between the two sets of experiments. Whereas we found that ferric oxide was without effect on the interaction of the carbons we employed, Cobb found that a coke prepared from coal to which the iron oxide had been added prior to coking was also much more reactive than his "pure"

[2] J. Am. Chem. Soc., *43*, 2055 (1921).

coke, indeed equally as reactive as that prepared with sodium carbonate. This suggests that in Cobb's experiments the influence of the iron oxide was exerted in the coking stage, giving as Cobb himself remarks "much finer grained, stronger and more homogeneous cokes." This conclusion is, indeed, identical with that suggested by Bergius as accounting for the effect produced in the hydrogenation process by the addition of iron oxide—the avoidance of danger of rapid polymerization due to the presence of sulphur in some form or other.

These examples teach a very definite lesson. They show that the processes broadly embraced under the title of carbonization are in reality quite complex. What, however, is of greater importance is that, by unravelling the complexity, by a more penetrating analysis of the individual steps in the general process, positive conclusions can be drawn as to better methods for the conduct of the process, positive steps can be taken (such as the addition of iron oxide) to control the undesirable elements in the process. The data cited indicate that carbonization is not merely the introduction of heat energy into a mass of complex hydrocarbon material, the removal of whatever volatile matter is evolved and the calm acceptance of whatever residues remain. They indicate that the real student of carbonization has it in his power to direct and to manipulate his materials to attain desired ends; that variation in those materials and in their manipulation call for the best efforts of the research mind.

An intimate knowledge of the chemistry of polymerization is only now beginning to be achieved—not at all through the researches of those interested in fuel, though, as we have seen, it is a most important aspect of their problem—but rather through those who are interested in synthetic rubber and plastics. It has emerged quite recently that many of the processes of hydrocarbon polymerization are not only accelerated by positive catalysts of the types already indicated in a previous paragraph (page 192) but may also be tremendously retarded by negative catalysts or inhibitors. Thus, the researches of Moureu and Dufraisse have shown that the polymerization of acrolein, to yield the plastic disacryl, is enormously sensitive to the action of inhibitors. Some recent studies in Princeton have shown that a large variety of substituted ethylenes, some hydrocarbon in nature, others substituted ethylenes such as the vinyl esters, are quite generally affected in their power to polymerize by

the presence or absence of inhibitors. Polymerization may be produced by heat, by light and by positive catalysts. The efficiency of the inhibitor can be very strikingly demonstrated by subjecting a vinyl compound, such as vinyl acetate, to the action of the ultraviolet light transmitted by thin pyrex tubing, in the one case alone, in the other case in the presence of about 0.1 per cent hydroquinone (a fair inhibitor). Simultaneous illumination of two such tubes to light of a given intensity will in a certain time interval turn the non-inhibited solution to a plastic solid polymer while the inhibited liquid remains substantially unchanged. (Demonstration.) The same holds true for thermal and catalytic polymerization. Phenols, polyphenols, primary, secondary and tertiary amines, aromatic hydrocarbons and a variety of other materials are efficacious in inhibiting such polymerization processes.

The student of carbonization or of hydrogenation of coal, knowing, therefore, of the importance of polymerization in his own operations, might therefore ask himself how far the operation of coke production is dependent on the action of inhibiting agents or, alternatively, how far the addition of known inhibitory materials prior to the carbonization or hydrogenation process would affect the progress of the reaction. This train of thought would suggest that the quality of oil used in the hydrogenation process might be a matter of prime importance in determining the efficiency of the work. For, since phenolic bodies in general are strong inhibitory agents, the use of oil fractions rich or poor in such materials might profoundly modify the progress of reactions occurring. So far as the present author is aware no systematic investigations of this kind are known, although a study of some of the recent patent literature relative to hydrogenation suggests that effects such as those here considered may have occurred without the reasons for the same being understood by the patentees.

A discussion of inhibitory agents and their application in fuel technology cannot be limited, however, to the problem of polymerization. This latter is, indeed, only a recent development of the general subject of inhibition which has hitherto been confined almost exclusively to the reactions of oxidation. A wide variety of recent research[3] indicates decisively that the operation of such additions to gasoline as tetra-ethyl lead, iron carbonyl, benzol, aniline is inhibitory in nature, that the added agents inhibit oxidation reactions

[3] For a useful summary, see Egerton, Nature, July (1928).

which are self-perpetuating and known to the physical chemist as chain reactions. These reactions of oxidation of hydrocarbons and of many other gases all reveal the same characteristics and must therefore possess in common this sensitivity to inhibitory agents though, naturally, in different degrees. This forces the conclusion that the development of ethyl gasoline is but the logical development of the early researches of Humphry Davy in 1817 on the influence of such materials as hydrogen chloride and silicon tetrafluoride on the lower explosibility limits of hydrogen.

The developments in the field of gasoline treatment to produce high compression engine fuels mean that attention must also be directed by the coal technologist towards the quality of his liquid fuels produced by hydrogenation or by carbonization at high or low temperatures. Either the quality produced must be adequate to the increasing demands made by the high compression engine or they must be modified in their characteristics by the addition of inhibitor. This does not, however, exhaust the possible applications of this new development. Since, as is evident from recent work by Hinshelwood,[4] Pease,[5] and Semenoff,[6] the simpler gases such as hydrogen, carbon monoxide and the less complex hydrocarbons also reveal the same chain-reaction characteristics as do the higher hydrocarbons in gasoline, it is pertinent to inquire how far the results with the gasolines may be transferred to the gaseous materials produced in the various stages of fuel technology. In particular, it may be asked how far the utilization of the gaseous products from coal in a variety of gas engine operations burning town's gas, water gas or blast furnace gas may not be improved by a restudy in the light of gasoline engine development. As is well known the power developed in gas engines is determined in part by the compression ratio employed. This latter is, in its turn, governed by the quality of the gas and its tendency to pre-ignition. Pre-ignition is the analogue in gas engine practice of knock in gasoline motors. Research, therefore, is needed to ascertain how far increase of compression ratio may be achieved in gas engine practice by incorporation, in the gases used, of inhibitory agents which shall overcome the tendency of the gas to pre-ignition. The problem is of necessity largely an economic one in so far as the particular application is concerned. We must be content here with

[4] Proc. Roy. Soc., *118 A*, 170 (1928).
[5] Proc. Nat. Acad. Sci., Washington, *14*, 472 (1928).
[6] Z. Physik., *48*, 571 (1928).

an emphasis upon the applicability of the principle of inhibition in the general field of gas engine practice.

There remains also the whole field of catalysis in the better utilization of fuel by-products. In so far as improved fuel technology leads to the production of heavy chemicals such as sulphuric acid and of fertilizers in the form of ammonia, to the manufacture of derivatives of tars and tar-oils, the part that the catalyst may play is large and continually expanding. Such an extended field is, however, beyond the possible limits of the present discussion. It must suffice to point out that the rapid developments in these fields are actually the assets of those intelligently engaged in the profitable development of coal processing and are also, at the same time, a constant threat to those who fail to pay adequate attention to their scope and to their possible influence on the direction of development in fuel treatment. The race is to the swift; it is of the essence of catalysis that the slow may be swift.

COAL PROBLEMS IN PERSPECTIVE

By The Right Hon. Lord Melchett, P.C., D.Sc., F.R.S.

London

Read by Grant B. Shipley

My first duty is to apologize to you on behalf of Lord Melchett for his inability to be present today. As you are all no doubt aware he has just paid a visit to this great country and Canada and had originally hoped to be able to extend his stay here to include this conference. He was looking forward particularly to meeting and addressing this important conference and is very disappointed that he is not able to do so. The very representative nature of the conference, the vital importance to all industrial countries of the problems to be discussed, and the auspices under which the conference is held, all combine to make it a matter of the deepest regret that he has been denied the privilege and pleasure of attending it and addressing you.

It is, however, my pleasant duty to deliver to you the address which he would have given and I will therefore do so without any further preamble.

The title of this address, namely, "Coal Problems in Perspective," naturally awakes in the mind a desire to look backwards into the past, to take a brief survey of the present position and to look forward into the future. Let us begin with the former. Coal is comparatively a newcomer into civilization. We have quite certain evidence of the existence of a highly developed civilization six thousand years before the beginning of the Christian era, evidence gathered, I may say in passing, by an Anglo-American expedition, and it is certain that civilization of a kind is far older than six thousand years. In comparison with this length of time coal came into use but the day before yesterday. In England, for example, we read interesting facts concerning its use in the reign of Edward the First.

The product so noted was outcrop coal which was often washed up on the seashore and which was therefore usually known as sea coal. Coal at first was received with very great disfavor. On a Patent Roll under date June 28, 1307, the following was recorded relating to the various prelates and magnates of the realm who

had been disturbed by the smoke of coal in operations where charcoal had formerly been used by smelters "whereby an intolerable stench diffuses itself in the neighborhood and infects the air, in consequence whereof the King commands the Mayor and Sheriffs of London and the Sheriffs of Middlesex and Surrey to make the proclamation that all persons wishing to exercise that mystery should cease to use coal." If the ordinance were not observed the offenders were to be punished by grievous fines! Fifty years before this Queen Eleanor had been forced to leave Nottingham Castle on account of the smoke of sea coal.

For centuries the wealthier classes in London regarded coal as inferior to both charcoal and wood and objectionable in its results. While in this country there may be few who would desire to burn coal in the open grate (a relic no doubt of its early history and for the same reasons) in Britain the majority of the population in spite of continuous appeals on behalf of fuel economy still prefer to see the flickering glow of the flame and the spiral ascent of the smoke.

There was an extraordinarily cheerful disregard of life and limb and general safety precautions among the early miners. I cannot resist quoting from an early English work which, though not dealing with a coal mine, shows the spirit. There was a young man in Derbyshire in the early part of the seventeenth century. He was later the well-known metallurgist Sir John Pethurst, and on this occasion was traveling in the charge of one Sir Thomas Bendish and he says: "I ask't whether I might be safely let down in the basket to see their works? They assured me that I might and so with Sir Thomas's consent (who in respect of his corpulency thought not fit to lead the way) I was let down not in the basket but on a strong stick laid across the Hook of the Rope."

When he got down the mine and arrived in the tunnel he says "I told my conductor that I could not keep my candle alight and at that instant both candles went out: Sir said he I pray you stay here and I will go fetch more candles for it is nothing but a Damp; at which words my spirits were much decomposed yet I had so much left as to crawl back to the shaft and suck't in as much air as relieved me; my conductor soon returned with more attandants to light me; but I was very unwilling to return again, but gave them librally something to drink, which the more obliged them to perswade me to see their works, assuring me that those Damps were not killing, but they had taken care (by keeping open the passage of

their waters) that no such accident should happen while I was there, and that they had good Aqua Vitae, Rosa Solis and good Ale to cheer me, with that I went into the mine where there constant lamps and candles, which they lighted for my sake did make the glitterings of the Ore very pleasant to me, by which I also saw the methods of digging and was well treated with their promised drinks, besides good beef and bread so as their liberality encreased mine, and then I was attended to the shaft, and so drawn up as I went down and on my gentle passage I thought of Vergila distick

> Dic quibus in Terris eris mihi magnus Apollo
> Tres Patiat Coeli spatium non complius ulvas.

But I was not edified by it, and so I came safe up and gave a pleasing account to Sir T. Bendish."

The most amazing remedies were used to restore miners overcome by fumes—for example we read that "when the damps exanimate a man at these coal pits they draw him up instantly and make a round hole in the earth, put his head in and cover it with fresh mould, which infallibly restores him."

Coal was first distilled about 1650 in order to recover some of its tar contents.

Speaking of early views of the nature of coal I cannot do better than quote your own distinguished fellow countryman Benjamin Franklin. "I am persuaded, as well as you, that the sea coal has a vegetable origin, and that it has been formed from the surface of the earth; but as preceding convulsions of nature had served to bring it very deep in many places and covered it with many different strata, we are indebted to subsequent convulsions for having brought within our view the extremities of its veins, so as to lead us to penetrate the earth in search of it. I visited last summer a large coal-mine at Whitehaven, in Cumberland; and in following the vein and descending by degrees towards the sea, I penetrated below the ocean, where the level of its surface was more than eight hundred fathom above my head, and the miners assured me that their works extended some miles beyond the place where I then was, continually and gradually descending under the sea. The slate which forms the roof of this coal mine is impressed in many places with the figures of leaves and branches of fern, which undoubtedly grew at the surface when the slate was in the state of sand on the banks of the sea. Thus it appears that this vein of coal has suffered a prodigious settlement."

I hope that I have not wearied you by quotations from sources obscure and otherwise. My object has been to suggest that until the commencement of the industrial revolution of the end of the eighteenth century coal was a novice in its application and a nuisance in its use. With the beginning of a mechanical age and with the application of steam to motive power coal as a source of fuel and power came into its own. The mechanical age, required iron for its implements instead of wood. The mechanical age demanded a cheap and constant source of power. It would not be unfair to say that the whole of the industrial revolution was based upon the application of coal to all major industrial processes. England took the lead in the industrial revolution because she had the inventive genius and the capacity of practical application. She was able to develop that lead and to maintain it because she had ample resources of coal with the further advantage that her most easily profitable coal fields were near the coast. Therefore, the steel works and engineering works were built near the coal fields. This had a double advantage. It reduced the export cost of British metallurgical and engineering products and concentrated the development of coalfields where a tremendous export trade in the raw material of power could be developed.

As must inevitably happen in the case of a rapid expansion in any industry, particularly at such a time of rapid transition as the inception of the industrial revolution, wages were low, conditions were deplorable and the conscience of the country was outraged. Hence it might fairly be said that the introduction of the Factory Acts in Britain was due in no small way to the horrible example afforded by labor conditions in the coal fields.

There are those of us who believe that the first phase of the industrial revolution has spent its force and that the second phase is well on its way towards practical results. Britain's great export trades of manufactured goods has been based upon the accessibility and quality of her home supplies of coal. Britain at the moment is undergoing a vital transition in her industrial organization. The old individualistic school born and bred in Manchester is giving way to a rational concept of industry. Instead of something like 3,000 separate colliery companies each working their pits according to their desires, wishes or whims there is a tremendous movement towards a modern organization of the industry.

Organization must, however, be considered divorced from the

science of coal. Coal, as no one knows better than yourselves, is now no longer regarded as merely one material; it is classified, bought on classification and is the subject of an immense amount of study and research. You in the United States of America are the greatest coal producers in the world. Great Britain with only about 2.5 per cent of the world's coal reserves produces about one-fifth of the world's consumption, raising about two hundred and fifty million tons per annum of the world's twelve hundred million tons.

Now it is probable that the domestic consumption of coal in any one civilized country is not particularly different in distribution from that which obtains in any other, and if we do not lay too great stress on any particular figure we shall be justified in drawing general conclusions from it. I have before me the distribution of the coal domestically used in Great Britain and I wish to comment on some of the items on the supposition that although they may not exactly hold for the world at large, they will form a very fair picture of the way in which we use our coal.

Let me take some figures; rather more than one-third is used for general manufacturing and similar purposes. The services of the collieries themselves take about one-eighth; railway locomotives about 7 per cent. Domestic consumption also takes a large fraction—say one-fifth. Now we know perfectly well that in all the above cases we are not using the coal anything like so economically as we can even under present conditions. That magnificent and impressive creature the railway locomotive, for example, usually develops an efficiency of about 8 or 9 per cent, and we could all go through each item and show how we could turn our coal to very much better purpose than we do at present.

The whole world realizes this and is quietly and steadily attacking the problem and with a large and increasing measure of success. Consider the generation of power for example. The thermodynamic fluid most commonly used for the production of power is steam. The hotter the steam is the more work you can get out of it and its temperature under practical conditions is a function of its pressure. Not so many years ago we were all quite proud of steam raising plant in which the boilers developed 200 pounds per square inch. Now we see huge stations being erected at vastly higher pressures than this. In this country I believe that you have even experimented with mercury as a substitute for steam because of the higher temperatures and consequent greater conversion into power which can be produced.

The point which I desire to bring out is that civilization is constantly tending and striving towards a more economical use of coal, and this is one of the factors which is militating and in a perfectly and proper and legitimate manner against the coal trade of the world. This movement must increase and strengthen and we should always welcome it. I take it that the problem of those engaged in producing coal is to tide over the period of over-production through which we are passing in such a way that what might be called the legitimate output of coal when used with the utmost economy will satisfy the needs of the world.

Let us look for a moment at the present position of the coal industry in Britain and discover whether there are any lessons to be learnt for the future. If there are any lessons to be learnt for the future from a study of the coal position in Britain they will be of universal application because Britain is the home of the coal industry. Before the War she had developed an export trade to Europe which was regarded as one of her main national assets. She had often exported her superior product to the United States, and that not only in times of labor upheaval here. Whole towns had been created in dismal surroundings in the coal-producing areas; whole series of villages and hamlets had been built depending entirely upon one industry. On the actual seaboard there were steel works and iron works and tin-plate works dependent for their prosperity upon a continuous and cheap supply of coal. The war came. The steel production had to be increased by an enormous percentage. Men were withdrawn from the coal fields who had an inherited skill which could not be replaced in efficiency by the hastily acquired skill of those who found the deepest drifts safer than the first-line trenches.

The war ended. The original denizens of the drifts reappeared to take back their peace time avocations. The substitutes were not to be displaced. The spurious prosperity of the War period and of the boom year of 1920 coupled with an over-rapid deflationary policy in finance led to the inevitable result of continuous turmoil and sporadic strikes. Foreign manufacturers accustomed to depend upon the continuous supply of British coal had to find other sources of fuel and motive power. Within a few years Britain found her export markets depleted and a home consumption not sufficiently expansive to make up the loss. Further, there was a problem caused by a surplus of near a quarter of a million men who were legally insured as belonging to the industry.

This was the position in Britain. Nor was the position in Germany very much better. Bereft of a part of her coal fields in Silesia and Lorraine the German export market was contracted and its sources of supply diminished. But Germany had had already to bear the fierce brunt of more than a generation of British competition. Her coal industry had accordingly organized itself through various coal selling associations which controlled production, regulated prices and saw that a fair price was obtained at home for the coal produced.

This system was started in 1893 and has successfully continued to the present day. A little difficulty was experienced at first in fixing prices of the various qualities and grades but this soon disappeared. All competent to judge are agreed that unorganized competitive selling of coal was bringing them to bankruptcy and that the procedure mentioned above saved their industry. It might not be going too far to say that in the uncertainty, confusion and depression of the post-war period, the coal industry of Germany was saved by its organization and reorganization.

It is difficult to compare in detail the coal problems of America with those of any European country. The tremendous and ever expanding home consumption of all manufactured articles in the United States gives the coal industry an advantage which that of Britain with its considerable dependency upon an export market does not enjoy. Moreover, on account of the widths of your seams and the easy application of mechanical devices to your coal-gaining you have advantages which are denied the other coal producing countries.

But you also have your disadvantages. Are your coal fields near the seacoasts? Are your cheapest coal producing areas always discovered where your heavy industries have been placed? Is your quality of anthracite, for instance, as pure and effective as that of Welsh anthracite?

What I am endeavoring to suggest is that the coal problems of the world are one. One country may have one particular advantage and another country may have another. In various lines of manufactured articles there are international arrangements which have been made and which have not only stabilized a particular industry within a country but have stabilized particular industries throughout the world. And there is nothing more important to the progressive development of industry than stabilization of various industries nationally, imperially and internationally.

One country may gain a purely temporary advantage during the course of labor disputes and stoppages in other countries, but that fact alone does not stabilize an industry even nationally. It seems to me that what is required is within the various countries, and some have gone further than others in this direction, national arrangements, not necessarily amalgamations, which shall so rationalize the coal industry that the productive power is brought into line with consumptive capacity. But to those countries considerably dependent upon export trade that alone will not suffice unless they are in some kind of understanding or arrangement with other coal producing countries. I am not advocating an international cartel, I am merely suggesting that the coal industry should bring itself into line with other modern industries.

As I have indicated the problem of the production of the right amount of coal and its proper distribution and marketing is one of the great industrial problems of the world with which all countries are faced in a lesser or greater degree. That you yourselves are experiencing it is shown in that admirable book of Professor Stockder of the School of Business in Columbia University in which he says, "we in the United States in recent years have experienced and still are experiencing great difficulty in adjusting our own coal industry to meet the requirements of an economic life." The present perspective of the coal trade is that it is threatened by two evils, one of them a good one as we would say in Ireland, namely the evils of wasteful competition and over-production—and the good evil of lessened trade due to constantly increasing efficiency.

I have already said that the coal industry in Britain is not an ancient one, but unfortunately it is ancient enough to have a tremendous volume of capital sunk in it. That capital has not always been wisely used. The profits made have very frequently been unequally divided, when the ultimate needs of the industry are considered. Owing to its natural condition the industry has frequently been subjected to industrial controversies. It is therefore all the more difficult to effect a complete rationalization of the industry even nationally.

But depressing as the coal situation in Britain may appear to be both to many at home and to a majority of outsiders, there is little doubt that the ultimate consequences upon the national prosperity of our country have been exaggerated. The coal industry of Britain is not played out yet; Britain herself certainly is not played out

industrially. Even in the coal industry the patient is not merely sitting up and endeavoring to take nourishment, it is looking round for means of salvation on this side of eternity.

Still there must be considerable reorganization and part of that reorganization should be undertaken promptly. For example, in almost any other branch of progressive modern industry it would seem folly and worse to continue working under unremunerative pits when the productive capacity is greater than the consumptive demand. Yet that is what is taking place in most coal producing countries of the world to-day.

Deficient as the means of coal-gaining are in many coal producing areas throughout the world; incomplete as has been the application of the latest technical developments and improvements to the mines, it is my firm belief that the main line of salvation lies in a better organization of the industry. It must commence nationally. It must be extended to embrace the European coal producing countries and ultimately the coal producing countries of the world. For there are many undeveloped countries which have contained tremendous reserves of coal. At the appropriate time and under the appropriate conditions these will be worked, and for the future of the industry throughout the world it is important that from the beginning the new fields and producing countries should be embraced in the frontiers of a rationalized industry.

I am not neglectful of the tremendous economies which could be effected by the internal reorganization on the technological side of individual pits and groups of pits. In a small country like Britain it is no idle vision of the future to visualize coal areas with central power stations in which its electrical power, its gas, its multitudinous coke-oven products, its smokeless fuel and its oil is distributed throughout the industrial areas of the country. Imagine what a boon such an organization would be to all productive industries, especially for example to the iron and steal industries, where the low price of the final product is so dependent for profit upon a cheap supply of coke and coal. It has been estimated, for example, that the addition of a million tons to the steel production of Great Britain would bridge that margin between depression and stabilization of the coal industry here. Further the organization suggestion would provide one of the most practical applications of industry to agriculture which could be contemplated, apart from the application of artificial fertilizers to the soil.

For when all is said and done coal must remain the basic source of fuel and power for many generations to come. Its reserves are ample. Coal mines may be a wasting asset but any natural product which does not return its yearly yield is equally a wasting asset. There was a time not many years ago when a famine in the supply of gold for the world was prophesied, but new gold fields have been discovered, new and more scientific processes for the separation of the precious metals from the ore have been discovered. So in the case of coal. He would be a bold man who would estimate within some thousands of millions of tons the coal reserves of Great Britain. He would be a bolder man who would estimate within some billions of tons the coal reserves of the world. Economy in fuel by all means as economy in every other national asset including man-power. But economy means gaining the most out of what is there.

I am not despondent about coal in perspective. It might be too sanguine for me to suggest to you that the day may not be far distant when Britain may render herself independent of outside sources of oil supply; when Britain will make her skies even in industrial areas that azure blue which the foreigner sees in reality and the Briton in fiction; when London even in November will be relieved of those throat teasing and eye-burning fogs which are not a part of an ancient history like the Tower of London, but are a part of her system of coal wastage.

Coal remains a basic national advantage of those countries which have ample reserves. Its national advantage would be greatly increased and the first fruits of its new effect upon other industries would be hastened if the coal industry could only bring itself into line with modern commercial, scientific, economic and administrative development. Those countries which are prepared to insist that their coal industry shall be rationalized, those countries which are prepared to apply modern technical advances in the production of coal, those countries which, irrespective of immediate results, will continue long period researches into fuel problems, will still see coal is King.

THE CRACKING OF LOW TEMPERATURE COAL TARS AND THE BERGINIZATION OF LOW TEMPERATURE COAL TAR IN PRESENCE OF CATALYSTS

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Part I. The Cracking of Low Temperature Coal Tars

INTRODUCTION

A considerable amount of attention has been devoted in quite recent years to attempts to elucidate the chemical composition of low temperature coal tars but little progress has been made in the utilization of such materials in commerce. It is known, of course, that primary tars from bituminous coals are difficult to handle and that they do not contain appreciable proportions of chemical entities of recognized technical worth. Their composition has been well summarized by Edwards (*J. S. C. I.*, 1924, T. 143–146) who, in researches dealing with the examination by distillation and extraction with solvents of two typical low temperature tars, showed that they were composed of the following constituents in indeterminate proportions: (*a*) Ulmin-like substances insoluble in ether but soluble in pyridine and phenols, (*b*) neutral oils, containing paraffin, naphthene and aromatic compounds, but composed chiefly of highly unsaturated hydrocarbons, (*c*) homologues of phenols (rhetinols), (*d*) Basic materials of novel character and smaller quantities of pyridine and quinoline bases (*e*) small proportions of carboxylic acids, traces of ether-insoluble bases and substances resembling ulmic acids. From the results of his investigation, Edwards concluded that "The absence of any products of known technical value particularly phenol, is abundantly proved and it is clearly shown that the high value placed on low temperature tar is not justified on present knowledge." The soundness of this generalization as regards individual chemical compounds is proved by the results of investigations carried out by Brittain, Rowe, Sinnatt and Parrish (Fuel, 1925, *4*, 263–9, 299–307, 337, 340; *J. S. C. I.*, 1926, 99–106 T.) but applied to groups of compounds, it required modification as will be shown later.

Recognizing, therefore, the low commercial value of primary tars

derived from bituminous coals, it occurred to one of us (A. E. D.) more than two years ago, that if the composition of the tars could be modified by thermal decomposition, products of greater utility might conceivably be formed and a new outlet established for these materials. Accordingly, work was commenced in 1925 on the cracking of typical low temperature tars, the object being to discover the conditions which would lead to the production of the maximum yields of motor spirit. Naturally, the low-boiling constituents of the tars investigated were not subjected to cracking conditions but were recovered and examined separately.

NATURE OF TARS EMPLOYED

The tars selected for investigation were of two types, designated throughout as A and B respectively. The former was produced in the early stages of the research by the carbonization of a South Yorkshire feebly-coking coal in a laboratory apparatus and later in a plant of semi-commercial scale, involving distillation of the coal in vertical, externally-heated retorts. The samples were received at frequent intervals in gallon batches, but a bulk sample of over 1,500 gallons was finally made available for more extended investigation. The earlier (laboratory prepared) consignments were extremely viscous, whereas the tar prepared on the large scale was quite mobile and possessed the properties of a high-grade primary tar. The difference in viscosity appeared to be due to a higher content of low-boiling constituents in the more mobile tar.

Tar B was manufactured on an essentially technical scale in vertical, continuous, externally heated retorts from a blend respectively of a steam coal and a strongly-coking coal. A sample of about 80 gallons was received early in 1926.

Typical analyses of the two tars are given below:

	A. Prepared on *small scale*	A. Prepared on *large scale*	B. Prepared on *large scale*
Specific gravity at 60°F.	1.038	1.035	1.042
Water content	10%	6%	2%
Tar acids	21%	—	26%
Products volatile below 200°C.	11.5%	20.2%	12.5%

EXPERIMENTAL

I. Recovery and Examination of Straight-Run Spirits

The first step necessitated the recovery, refining and testing of the spirit present as such in the tars. A number of distillations were carried out according to the nature of the residue required for cracking purposes, but the following illustrations will suffice. Three batches, each of 6 liters, of tar A (large scale) were distilled to varying percentages of residue. In the first, A_1, distillation was continued until a 34 per cent pitch remained in the still, steam being admitted when the specific gravity of the issuing distillate exceeded 1.00. The second distillation (A_2) was carried through in the same way until only water was passing through the condenser, the residue in this case being more in the nature of coke than pitch. The oil distillate in the last stages was a grayish-yellow waxy solid which was soluble, with difficulty, in the main bulk of distillate. The third method, A_3, was concerned with removing only the constituents volatile below 200°C. To this end, a 30 per cent distillate was taken off, this being subsequently redistilled to 200°C. through a glass column filled with glass beads, the distillate bottoms being added to the main bulk of residue obtained in the preliminary distillation. The first two distillates (A_1 and A_2) were similarly redistilled to 200°C., the residues in these cases constituting cracking stock.

Tar B was distilled in a somewhat similar manner to leave, in two experiments, 40.0 and 38.4 per cent of pitch, the resulting distillates being topped to 200°C. to recover the straight-run spirit and the residues being utilized as cracking stock. A further run was carried out on tar B in which the spirit B_2 boiling below 170°C. was isolated.

The crude spirits so obtained contained considerable proportions of tar acids, which have recently been stated by Egloff and Morrell (*Oil and Gas J.*, December, 1926, p. 156) to be not undesirable constituents of motor spirit. With this opinon, however, we cannot agree, partly because of the dangers of handling such materials (tar-acids blister the skin) but chiefly because phenols are not completely miscible with many petroleum spirits. Consequently, the tar-acids were removed completely by agitating the crude spirit with strong aqueous caustic soda. The residual crude hydrocarbons plus a small content of basic compounds, were then subjected to a variety of refining methods as follows:

1. Refining with Acid and Alkali. Portions of the crude spirit

hydrocarbons from each tar were agitated in succession with 1 per cent of strong sulphuric acid, 5 per cent of 10 per cent caustic soda and then water. The acid was used in two stages, 0.25 per cent in the first and 0.75 per cent in the second wash, each of which occupied 20 minutes. The partially refined spirits were then redistilled in a glass flask through the 12-inch glass column used throughout the work to a final vapor temperature of 200°C. A light soda wash after redistillation completed the initial treatment. It was found that whereas the refined spirit B was water-white in color and possessed a sweet odor, refined spirit A was sour and slightly yellow and became brown after standing for three days. The latter was therefore further refined with 0.5 per cent of acid in two stages, followed by soda and water washes, redistillation to 195°C. and a final light soda treatment (1 per cent of 1 per cent caustic soda). The liquid was now water-white and sweet and no reversion in color or smell could be detected after standing for a week in the laboratory.

2. Refining with Sodium Hypochlorite. Since spirit A had proved somewhat difficult to refine with acid, the efficiency of sodium hypochlorite was next tried. Sodium and calcium hypochlorites are employed with excellent results in the large scale treatment of Persian and other crude spirits and as the method has been carefully standardized, it was felt that useful comparative results would be obtained. The crude hydrocarbon spirit A was therefore refined as follows. A preliminary soda wash was succeeded by agitation with 0.31 N sodium hypochlorite, using 1 gram of chlorine per liter of spirit in each of two treatments. A final soda wash and redistillation to 200°C. gave a liquid which was sour and yellow. It was therefore, next subjected to acid treatment, 0.5 per cent of strong sulphuric acid being used in two successive washes. The usual soda treatments, both before and after a second redistillation to 200°C., completed the scheme. The spirit so refined was sweet and water-white but very slight deterioration in color was noticeable after several days.

3. Refining with Acid and Clay. A straight run spirit from tar B constituting 5 per cent of the crude dry tar and having a final boiling point of 170°C. was also prepared. This crude spirit contained 13 per cent of tar acids which were removed in the usual way by extraction with caustic soda. The resulting hydrocarbons were treated with varying percentages of diluted sulphuric acid (80 per cent by weight) and agitation with 5 per cent of a refining clay followed by distillation to 170°C. It was found that the quantity of acid re-

quired, in conjunction with the clay, to give a water-white stable spirit was 2 per cent by volume, the refining loss being 16 per cent.

TABLE I

REFINING OF STRAIGHT RUN TAR SPIRITS

	CRUDE SPIRIT FROM TAR				
	A			B	
	A_1	A_2	A_3	B_1	B_2 (170°C.)
Yields on dry tar:					End point
Specific gravity of crude spirit	0.898	0.907	0.910	—	0.856
Tar-acid content	27	28	29	29	13
Hydrocarbons refined with 1 per cent acid	1	1.5	Hypochlorite and 0.5% acid	1	Acid and clay
Refining loss, per cent	25	33*	37†	22.5	16
Yield of crude spirit on dry tar, per cent	18	20.2	21	12.5	5.0
Yield of crude spirit hydrocarbons	13.2	14.5	14.9	8.9	4.4
Yield of refined spirit hydrocarbons	9.9	9.7	9.4	6.9	3.7
Properties of refined spirits:					
Specific gravity	—	0.836	0.838	0.845	0.825
Initial boiling point (Engler), °C	—	75	82	91	—
Vol. to 100°C., per cent	—	0.5	F.d.	—	—
Vol. to 125°C	—	18	15	3.5	—
Vol. to 150	—	58	55	34.5	—
Vol. to 175	—	90.5	89	81	—
Final boiling point, °C	—	190	192	197	—
Anti-pinking efficiency (benzol = 100)	107	Not tested	96	83	98

* Redistilled to 195°C.

† Twenty-five per cent loss with hypochlorite plus 12 per cent loss with acid.

Complete details of refining and properties of the resulting spirits are given in Table I.

The engine tests were carried out in a Thornycroft experimental engine, the compression ratio of which can be varied during test.

It will be observed from the above that the spirit hydrocarbons occurring in the two tars are amenable to refining with the usual agents but that the losses are heavy. This appears to be due principally to polymerization of certain of the constituents, there being invariably a large residue remaining on redistillation after chemical treatment. The specific gravities of the refined spirits are higher than is customary with petroleum spirits indicating a low content of paraffin hydrocarbons. This inference is borne out by the highest useful compression ratios (H. U. C. R.) of the spirits showing that these products possess anti-knock properties approximately equal to those of benzol. These materials will therefore be particularly valuable for blending with petrols which are prone to pinking. Their lack of substantial proportions of constituents volatile below 100°C. would necessitate their being employed solely for this purpose, though their boiling range would be improved by adding to them the light spirit scrubbed from the gases in the carbonization of the original coal.

II. The Cracking of Tar Residue and Distillates

The preliminary cracking experiments were carried out in a pressure apparatus which was designed and constructed in the Anglo-Persian Oil Company's Research Laboratories. It consisted of an autoclave of 450 cc. capacity, to which was attached a cover fitted with a thermometer pocket and a jacketted reflux condenser. The cover, with its attachments, was secured to the bomb by means of five stout studs and nuts, a metal to metal joint insuring gas tightness. The top of the reflux was fitted with a pressure gauge and release valve, the latter leading through a metal condenser to graduated liquid and gas receivers. Heating of the autoclave was effected in a specially constructed oven, well lagged on all sides with asbestos-magnesia paste. The heat was provided by a series of gas jets spaced along a small combustion chamber, the hot gases being driven by a fan into a second compartment which contained the bomb. After circulating freely around the autoclave, a portion of the gases returned along the bottom of the oven to the combustion chamber, whilst the remainder escaped into the air. To obtain exact temperature control both of the oven and autoclave contents, a pressure regulator and sensitive manometer were provided in the gas circuit,

thermocouples being also inserted in the oven and the bomb. The fan used to circulate the hot gases rested in a water-cooled bearing and was driven by a small motor. The efficiency of the heating device was such that the temperature of the autoclave could be raised to 400°C. in less than an hour, and could be maintained constant to one degree for a long period. During the course of over 100 experiments with the apparatus, the metal to metal joint has been refaced on only one occasion, whilst the fan, which normally is heated to redness, has suffered no deterioration.

In carrying out an experiment, the bomb was weighed empty and then with its charge of oil or tar (usually 300 cc.) the residue at the completion of the run also being weighed. The distillate (if any) and the uncondensed gas were measured and the density of the latter determined. Thus a very accurate balance of yields of products could be ascertained. Finally, it was possible to conduct an experiment in such a way that the whole of the products, except a certain amount of gas, could be retained in the apparatus throughout, or to allow the light liquid products to distil over. Both methods of cracking were adopted, as will appear in the sequel.

1. Cracking of Residue from Tar A. The material first selected for cracking was the residue obtained by removing from tar A the products volatile below 200°C. A laboratory prepared sample of the crude tar was topped to 200°C. in an iron still, there being collected 6 per cent of water, 11 per cent of crude spirit and 89 per cent of residue, the spirit and residue being calculated on the crude dry tar.

The cracking stock, which was an extremely viscous mass, possessed the following properties:

Specific gravity at 60°F.	1.071
Initial boiling point	187°C.
Vol. to 200	Nil
Vol. to 225	6%
Vol. to 250	15%
Vol. to 275	23%
Vol. to 300	31%

A total of 13 cracking experiments was carried out on this stock, the experimental conditions being varied through wide ranges. Thus in the first three experiments, the products were not allowed to distil over during cracking, a certain amount of gas being liberated, however, to maintain the pressure within safe limits. The pressures and temperatures were taken to a maximum of 550 pounds per

square inch and 441°C. respectively for a period of 70 minutes but even under these drastic conditions, the highest yield of crude spirit was only 7.5 per cent of the stock used. Since, further, the spirit contained 30 per cent of tar-acids, the total production of hydrocarbons boiling below 200°C. was only 5 per cent.

Accordingly, in the next three experiments, cracking was made to take place in two stages. In the first, the temperature was raised to 432°C. and maintained there for 35 minutes, the maximum pressure being 600 pounds. The autoclave was then allowed to cool somewhat and the cracked spirit distilled off. The residue in the bomb was finally heated to 464°C. for 15 minutes at a pressure of 400 pounds per square inch. The cracked spirit from both stages was bulked,

TABLE II

	EXPERIMENT 48—1 STAGE	EXPERIMENT 50—2 STAGES	EXPERIMENT 54—PRESSURE DISTILLATION
Specific gravity of stock	1.071	1.071	1.078
Maximum temperature, °C	415	464	451
Average pressure per square inch, pounds	200	560:370	160
Pressure distillate, per cent	—	—	31.6
Crude spirit to 200°C. per cent	7.5	12.8	12.6
Tar acids in spirit, per cent	30	33	40
Hydrocarbon spirit, per cent	5	8.5	7.6
Gas, volumes	27	73	69
Residue—coke or pitch, per cent	74	49	62.7

giving a yield of 12.8 per cent of crude spirit or 8.5 per cent of crude hydrocarbons spirit. Finally, in the concluding experiments of this series, distillation was allowed to take place during cracking, the following being a typical example. The tar was distilled at an average pressure of 160 pounds, the temperature increasing to a maximum of 451°C. The pressure distillate, 31.6 per cent by volume of the charge, was redistilled at the ordinary pressure to 200°C., the yield being 12.6 per cent. The cracked spirit so prepared contained 40 per cent of tar-acids, the production of hydrocarbon spirit being, therefore, 7.6 per cent. Details of typical experiments are given in Table II. It is apparent from the above that little is to be expected from the thermal decomposition of the tar residue. The yields of cracked spirit are extremely low whilst coke or pitch pro-

duction is excessive. No further work with this unpromising material was undertaken. It being clear that for successful cracking, substances with a substantially lower content of pitch must be employed.

2. *Cracking of Heavy Distillate from Tar A.* The cracking stock used in the following series of experiments was prepared by steam distillation of the crude tar A to coke and redistillation of the distillate to 200°C. Five liters of the laboratory prepared tar gave 6 per cent of water, 11.7 per cent of crude spirit, 66 per cent of heavy distillate and 22.3 per cent of coke, the spirit, heavy distillate and coke being calculated on the dry tar. The 11.7 to 77.7 per cent distillate had the following properties:

Specific gravity at 60°F.	1.040
Initial boiling point	198°C.
Distillate to 200°C	Nil
Distillate to 225	9%
Distillate to 250	24%
Distillate to 275	35%
Distillate to 300	48%

Three experiments were carried out employing in each the method of pressure distillation. Only the results of one will be quoted, as the differences in yields of products were within the range of experimental error. A charge of 300 cc. of the tar distillate was distilled at an average pressure of 480 pounds per square inch, the temperature of the contents of the bomb rising to a maximum of 450°C. The gases passing through the liquid receiver were scrubbed with charcoal and the latter subsequently steam-distilled, the light spirit so recovered being added to the pressure distillate. The latter, 30 per cent by volume of the charge, was then topped to 200°C. in the usual way and the crude spirit shaken with caustic soda. The yields were: crude spirit 14.8 per cent (tar-acid content 30 per cent); hydrocarbon spirit 10.4 per cent; gas 80 volumes per volume of charge; coke 60 per cent by weight. The preliminary experiments with tar A gave, therefore, very disappointing results, and as the stock of material had become exhausted, the investigation was temporarily suspended.

3. *Cracking of Tar B Distillates.* Having regard to the experience gained in handling tar A, it was decided to utilize as the main cracking stock a distillate substantially free from pitch. Opportunity was taken at the same time to prepare two pitch residues for examination from the point of view of their suitability as road surfacing or briquetting materials. Two separate batches of the crude tar were

therefore distilled to leave respectively 45 and 35 per cent of pitch in the still. Superheated steam was admitted when the whole of the water in the tar had passed over. The distillates were separately topped to 170°C; the yields and properties of the several products are given in Table III.

The 44.3 per cent pitch was obviously very soft and only moderately ductile, the other being brittle and hard. Neither of the two samples could be used for briquetting or road-surfacing purposes.

The crude straight-run spirits were combined, refined and tested as described in the first part of this paper.

TABLE III

	FIRST DISTILLATION	SECOND DISTILLATION
Water (on crude wet tar)	2%	2%
Crude spirit to 170°C. (on dry tar)	4.45%	5.65%
Topped distillate (on dry tar)	51.2%	60%
Pitch (on dry tar)	44.35%	34.35%
Specific gravity of crude spirit	0.858	0.856
Tar-acid content of crude spirit	13%	13%
Specific gravity of topped distillate	0.986	0.995
Properties of pitch:		
Loss on heating for 5 hours at 163°C	18.2%	12.4%
Softening point (ball and ring)	44°C.	58.5°C.
Flash point—open cup	170°C.	205°C.
Penetration	Over 200 @ 15°C.	10.5/5 sec./50 grams/ 25°C.
Ductitility at 15°C	Over 100	Nil.

The topped distillates were also combined and dealt with in the following manner. About one-third of the whole was set aside as cracking stock B_1. The remainder was thoroughly agitated with strong caustic soda to remove tar acids, the neutral oil remaining after washing with brine and drying being used as cracking stock B_2. The alkali solution of tar-acids was neutralized with carbon dioxide the liberated phenols constituting cracking stock B_3. The crude tar-acids contained water both in solution and suspension. They were therefore distilled to remove the bulk of water, though it was not found possible to dehydrate them completely. The fractions isolated from the tar distillate were: neutral oil, 52.5 per cent; phe-

nols, 29 per cent: there being a loss of 18.5 per cent. The loss was accounted for by a number of factors, including solubility of phenols in water, the deposition of a brown powder at various stages in the operation and difficulties in manipulation.

The essential properties of the three cracking stocks were as follows:

Cracking stock:	B_1	B_2	B_3
Composed of	Neutral oil and phenols	Neutral oil	Phenols
Specific gravities	0.992	0.956	1.055
Tar acid content	34%	Nil	100%

Each of the above materials was subjected to pressure distillation in the autoclave, two runs being carried out on the first two and one only on the third. In order to obtain comparable results, one experiment on each material was conducted so that distillation occupied about 140 minutes from first to last drop. The other runs, utilized a longer time for distillation in an endeavor to increase the degree of cracking.

The pressure distillates were collected in the usual way and their volumes and specific gravities noted. An Engler distillation was then carried out, the fraction to 200°C. being collected and distillation continued to 225°C. to give results comparable with American practice. The fraction between 200° and 225°C. was returned to the residue remaining in the flask, this being denoted in Table IV as Diesel oil. The crude spirits were extracted with strong caustic soda to remove phenols but there was insufficient material produced to carry out refining tests.

The essential experimental and other details are given in Table IV. The results of these experiments may be summarized briefly as follows:

a. The cracking of tar-acids results in the production of simpler tar-acids, gas and coke. Hydrocarbons are not formed in appreciable quantities.

b. As a corollary to the above, cracking of the mixed neutral oil and tar-acids has given results which are approximately the mean of those from the thermal decomposition of the neutral oils on the one hand and crude tar-acids on the other. Thus there is no apparent interaction between the hydrocarbons and the tar-acids during decomposition.

c. The employment of more intense cracking conditions has given

TABLE IV

CRACKING OF FRACTIONS OF TAR B

	NATURE OF STOCK				
	B_1 (neutral oil + tar acids)		B_2 (neutral oil)		B_3 (tar acids)
	Experiment 104	Experiment 105	Experiment 106	Experiment 107	Experiment 108
Specific gravity of stock	0.992	0.992	0.956	0.956	1.055
Distillation time, minutes	140	170	135	230	135
Average pressure, pounds per square inch	250	325	240	250	300
Temperature during distillation, °C.	407/510	421/516	410/500	408/501	390/500
Yields by volume on stock:					
Pressure distillate, per cent	74	70	75.5	65.2	72.4
Crude spirit to 200°C., per cent	31	30.4	26.1	29.6	36.2
Crude spirit to 225°C., per cent	52.5	50.2	38.7	41.3	58.7
Diesel oil (P. D. bottoms), per cent	41.7	37.6	49.4	35.4	30.8
Gas, volumes	69.3	84.1	63.8	101	69.6
Water, per cent	1.3	1.3	Nil	Nil	5.4
Yields by weight:					
Pressure distillate, per cent	71.3	66.6	72.4	62.2	64.7
Spirit to 200°C. per cent	28.2	27.5	22.7	25.8	—
Diesel oil, per cent	41.8	37.9	49.7	36.2	—
Water, per cent	1.3	1.3	Nil	0.2	5.3
Coke, per cent	21.2	24.6	20.2	26.8	23.6
Gas and loss, per cent	7.5	8.8	7.4	10.8	6.4
Specific gravities:					
Pressure distillate	0.960	0.957	0.917	0.912	1.020
Spirit to 200°C.	0.905	0.900	0.829	0.829	Water present
Diesel oil	1.008	1.008	0.978	0.978	—
Hydrocarbon spirit	0.833	0.833	0.829	0.829	—
Tar acid contents:					
Spirit to 200°C., per cent	34	33	4	4.5	100
Diesel oil, per cent	47.5	47.5	5	5	100
Yield of hydrocarbon spirit, per cent	20.5	20.2	25.0	28.3	Nil

higher yields of spirit, gas and coke in the case of the neutral oil but slightly less spirit in the case of the mixed oil fraction.

d. The quantity of cracked hydrocarbon spirit produced approximates to 20 per cent of the stock used, which is equal to 11.12 per cent of the crude dry tar.

III. Cracking of Tar Distillates on a Larger Scale

The experiments described in Part II of this paper had given quantities of cracked spirit totally inadequate for refining and engine tests to be carried out. A larger plant was therefore constructed, the design being similar to that of the smaller apparatus. The autoclave, which normally received a charge of one gallon of cracking stock, was fitted with a cover to which was attached a thermometer pocket and a reflux condenser. The latter consisted of a cold-drawn steel tube of one inch internal diameter, the length being 4 feet 6 inches. The top of the column was provided with a head, drilled out to take a short thermometer pocket, pressure gauge, release and safety valves and outlet to a condenser. The last named, 8 feet in length, conducted the liquid products into a graduated Wolff bottle, the uncondensed gases thence passing through a sensitive meter into the atmosphere. The oven in which the bomb was heated was constructed of a stout metal casing, lagged internally on all sides with a 3 inch thickness of Newtempheit and a 1½ inch thickness of Nonpareil bricks. The flames from six Fisher burners were directed into a combustion chamber at the bottom of one end of the oven, the hot gases passing along flues into a compartment containing the autoclave. Thence they were withdrawn by means of a fan, which rotated in a shroud and at once came under the action of a baffle. The latter caused a portion of the gases to be deflected into the combustion chamber for recirculation, the remainder being allowed to escape into the air through a short chimney containing a damper. Thermocouples were placed in the oven, the bomb and in the vapor space at the top of the column, a pressure regulator and manometer in the 1½ inch gas main assuring very accurate regulation of temperature.

The joints in all cases were formed of metal-to-metal facings these having been previously found to be extremely efficient and durable. The thermal efficiency of the heating system was of a high order, it being possible to raise the temperature of the bomb and its contents to 400°C. in two hours and to maintain the temperature constant for any desired length of time.

In carrying out the experiment, the material to be cracked was weighted into the bomb, which, after assembly, was conveyed to the oven on a small overhead runway. At the conclusion of a run, the coke or other residue was removed and weighed, the orifice at the top of the bomb being suffieiently large for the insertion of cleaning tools and inspection lamp.

Experimental. Two cracking stocks were prepared from tar A by distilling the crude to leave residues of 34 and 27.4 per cent respectively, the distillates being subsequently redistilled to separate the fraction volatile below 200°C.

Tar B was dealt with somewhat differently. Two samples, each of 6 liters, were distilled to approximately 40 per cent pitch residues, steam being employed in one operation and reduced pressure in the other. The object of using a vacuum was to compare the pitch so produced with that obtained by steam distillation. No marked differences, however, could be observed, neither sample being of commerical value except as fuel. The two distillates were bulked, the tar-acids and bases removed in the usual way and the neutral oils distilled to 200°C. Cracking stock B, therefore, was composed of heavy distillate hydrocarbons.

The essential results of treating the tars as described above were as follows:

	First	*Second*
Tar A:		
Constituents below 200°C., per cent	18.0	20.2
Hydrocarbons below 200°C., per cent	13.6	14.6
Tar-acids below 200°C., per cent	4.4	5.6
Residue of distillate, per cent	48.0	52.4
Pitch or coke, per cent	34.0	27.4
Tar B:		
Hydrocarbons below 200°C., per cent	8.2	
Heavy hydrocarbons, per cent	27.1	
Tar acids, per cent	21.1	
Bases, per cent	1.4	
Pitch, per cent	42.2	

Cracking of the three materials was effected by distillation under pressure, the essential experimental details, yields and properties of products being shown in Table V. For comparative purposes, the results of cracking a heavy fuel oil derived from Persian crude are included.

Refining of Cracked Spirit Hydrocarbons. The cracked spirit

from tar B was refined in the usual way with 1 per cent of strong sulphuric acid and alkali. After redistillation to 200°C. the refined spirit was sweet and water-white and did not revert in color or odor after standing for some weeks in the laboratory. The tar A cracked

TABLE V

PRESSURE DISTILLATION OF TAR DISTILLATES AND HEAVY FUEL OIL

	MATERIAL CRACKED			
	Tar A—20 to 66 per cent distillate	Tar A—20 to 72.7 per cent distillate	Tar B—Heavy Hydrocarbons	Persian Fuel Oil
Specific gravity of charge	1.006	1.019	0.956	0.895
Volume of charge, cc	2563	2800	2400	4035
Time of distillation, first to last drop, hours	4.25	4.25	4.25	4.25
Temperature of oil during distillation, °C.	403/37	423/43	418/53	410/50
Average pressure, pounds	170	185	150	155
Yields by volume of stock:				
Pressure distillate, per cent	64.3	48.2	67.5	73.6
Crude hydrocarbon spirit, per cent	16	11.8	24.2	56.7
Crude heavy hydrocarbons, per cent	31.6	15.4	43.3	16.9
Tar acids, per cent	16	19.4	Nil	Nil
Bases, per cent	0.7	1.6	Nil	Nil
Gas, volumes	71	112	93.2	94
Yields by weight of stock:				
Pressure distillate, per cent	61.1	44.8	64.6	63.9
Coke, per cent	29.2	42.0	24.0	20.9
Gas and loss, per cent	9.7	13.2	11.4	15.2
Specific gravities:				
Pressure distillate	0.956	0.948	0.917	0.777
P. D. hydrocarbons	0.940	0.897	0.917	0.777
Spirit	0.836	0.796	0.802	0.749
Spirit yield hydrocarbons on crude tar or oil, per cent	7.7	6.2	6.56	36.8

spirit, like the straight-run spirit, was found not to be amenable to refining with 1 per cent of acid but, with sodium hypochlorite and 0.5 per cent of acid, a very pale yellow liquid of pleasant odor was obtained. The properties of the two refined cracked petrols are shown in Table VI.

It will be observed that the yields of crude cracked spirits obtained from the various tar fractions are considerably less than that from Persian fuel oil, the quantity of coke simultaneously produced being greater. It would appear, therefore, that the low temperature tar

TABLE VI

	SPIRIT A	SPIRIT B
Refined with	Hypochlorite +0.5% acid	1% acid
Refining loss, per cent	20	18
Specific gravity @ 60°F	0.791	0.783
Initial boiling point, °C	56	45
Distilled to 75°C., per cent	F.d.	3
Distilled to 100°C., per cent	4	12
Distilled to 125°C., per cent	22.5	29
Distilled at 150°C., per cent	51.5	54
Distilled at 175°C., per cent	84	83
Final boiling point, °C	194	196
Yield of refined spirit on crude tar, per cent	5.6	5.25
Anti-knock efficiency (benzol = 100)	50	40

TABLE VII

	SUBSTANCE CRACKED					
	Tar A				Tar B	
	89 per cent residue*	11.7 to 77.7 per cent distillate	20 to 66 per cent distillate	20 to 72.7 per cent distillate	5 to 56.7 per cent distillate	19 to 70 per cent hydro-carbons
Autoclave used	Small	Small	Large	Large	Small	Large
Straight run spirit, per cent	8.2	8.7	13.6	14.6	4.4†	8.2
Cracked spirit, per cent	7.6	6.86	7.7	6.2	11.1	6.6
Total, per cent	15.8	15.56	21.3	20.8	15.5	14.8

* Laboratory-prepared crude tar.
† To 170°C.

distillates are very inferior cracking stock and that the possibility of utilizing them for such purposes on a commerical scale, bearing in mind the difficulty of separating and disposing of the tar acids, would be problematic.

On the other hand, the cracked spirits can be refined by conventional methods, they contain a higher proportion of constituents

volatile below 100°C. than is present in the straight-run petrols and they possess valuable anti-knock properties. They will be useful, therefore, for blending with petroleum spirits.

The yields of crude straight run and cracked hydrocarbons spirit, based on the dry raw tar, obtained by pressure distillation are given in Table VII.

PART II. THE BERGINIZATION OF LOW TEMPERATURE COAL TAR IN PRESENCE OF CATALYSTS

The cracking experiments described in Part I having given disappointing results, the effect of heating a tar residue under high hydrogen pressure was next investigated. The material selected was tar B, the raw tar being deprived of all constituents volatile below 200°C. by distillation. The residue of the tar, which was used in the experimental work, was a viscous black mass with specific gravity 1.076 at 60°F. The apparatus consisted of a cylindrical steel bomb having a capacity of 500 cc. The autoclave was fitted with a removable head carrying the usual metal-to-metal conical joint and was supplied with a pressure gauge, gas valve and thermometer pocket, the whole being housed in a bomb-proof shelter. The method of operation was as follows. Weighed quantities of the topped tar (150 grams approximately) and of catalyst were charged to the autoclave which, after assembly, was placed in a horizontal position over a line of gas jets. Hydrogen was then admitted from a cylinder to an initial pressure of from 85 to 100 atm. and the apparatus constantly rotated whilst heat was applied. By employing a sensitive manometer on the gas line and covering the bomb with a sheet metal hood, it was found possible to maintain the temperature constant to a few degrees. Temperature and pressure readings were taken at intervals of five minutes and the temperatures plotted on a logarithmic scale to enable a time factor at an average reaction temperature to be ascertained. After the bomb had cooled to room temperature, the pressure was noted and the treated tar removed and distilled to 300°C. under standard conditions, the specific gravities and phenol contents of the distillates being finally determined.

The chief experimental details are given in Table VIII.

It will be observed from the above figures that even in absence of a catalyst, appreciable quantities of hydrogen have been taken up by the tar and that this absorption has not been appreciably increased

TABLE VIII

	EXPERIMENT NUMBER										
	1	2	3A	3B	4	5A	5B	6	7	8	9
Catalyst	None	Zinc oxide	Nickel oxide		Ammonium Molybdate	Ammonium molybdate		Barium peroxide	Sodamide	Tungstic acid	Roseo
Initial pressure, atmospheres	85	83	85	83	83	95	87	94	87	80	77
Maximum pressure, atmospheres	183	198	170	186	160	199	270	230	228	190	185
Final pressure (cold), atmospheres	43	45	55	35	18	20	45	45	52	40	32
Loss in pressure, atmospheres	42	38		78	65	117		49	35	40	45
Maximum temperature, °C	462	463	400	468	467	466	467	480	482	482	481
Average temperature, °C	455	458		462	461	462	462	479	476	479	477
Time, minutes	48	46		47	48	50	37	42	51	40	43
Specific gravity of product	1.040	1.031	1.020		1.012	—	0.969	1.031	—	—	—
Spirit to 200°C., per cent	14	19	22		17.5	—	30	21	21.5	21	24
Distilled to 300°C., per cent	51	54	61		57.5	—	63	58	48	57	55
Specific gravity of distillate	0.980	0.960	0.955		0.948	0.915		0.958	0.964	0.971	0.944
Phenols in distillate, per cent	35	32	32		26	14		35	32	32	22
H_2 used, per cent weight	0.86	0.78	1.6		1.4	2.4		1.0	0.73	0.90	1.0

by the use, as possible catalysts, of zinc oxide, barium peroxide, sodamide and tungstic acid.

Reference to the phenol contents of the distillates shows also that these materials, even in presence of hydrogen, have had no effect in reducing the phenolic components of the tar to hydrocarbons. It is worthy of note, however, that zinc oxide gave a higher yield of spirit than was obtained in the blank experiment under almost identical conditions, the similar observations with sodamide and tungstic being vitiated by the higher temperatures employed. It may be concluded, therefore, that zinc oxide, barium peroxide, sodamide, and tungstic acid do not function as catalysts in the berginization of low temperature tar but that zinc oxide favors cracking.

The effect of nickel oxide is instructive. The maximum pressure attained during the experiment was considerably lower than in runs 1 and 2 and it was concluded, therefore, that hydrogen was being rapidly absorbed by the tar. On cooling, a fresh charge of hydrogen was admitted to the bomb and the materials treated under the same conditions for a further period. Although the total absorption of hydrogen was 1.6 per cent by weight of the charge, the phenol content of the distillate to 300°C was practically equal to that of the distillate recovered in the blank experiment. The loss in hydrogen pressure was partly due to reduction of the nickel oxide, the tar itself taking up 1.3 per cent by weight of hydrogen. This relatively high degree of hydrogenation appears to be directed, not towards reduction of phenols, but to the production of a large yield of lower boiling products as was apparent from the distillation curve and specific gravity of the product.

Pentammine cobaltic chloride (Roseo) and ammonium molybdate, which was converted to oxide under the conditions employed, gave, however, the most interesting results. In the former case, not only were the hydrogen absorption and spirit formation of a high order but the phenol content of the distillate was considerably lower than in the case of the blank experiment. Consequently, it may be concluded that roseo behaves as a catalyst in the reduction of phenols under high hydrogen pressure. The same conclusion may be drawn with respect to the action of ammonium molybdate (see run 4). In order to test the efficiency of the latter reagent in greater detail, experiment 5 dealt with hydrogenation of the tar in two stages, a fresh charge of hydrogen being admitted to the bomb at the conclusion of the initial treatment. In this experiment, very

profound hydrogenation occurred, as was evidenced by the following factors: (*a*) low specific gravity of product, (*b*) high yields of spirit to 200°C. and of distillate to 300°C., (*c*) low phenol content of the distillate, (*d*) production of 5 per cent of water by weight of original tar charged. Molybdic oxide therefore appears to be an energetic hydrogenation catalyst and its use as such has been patented by the I. G. of Germany.

PART III. HYDROGENATION OF CRESYLIC ACID IN THE VAPOR PHASE

In Part II of this paper, a method was described by which the phenols in low temperature tar can be reduced substantially to hydrocarbons by hydrogenation under pressure in presence of ammonium molybdate and the pentamine cobaltic chloride. It became of interest to ascertain if the same result could be achieved at atmospheric pressure since there are obvious objections to the use of the high pressures required in berginization. For this purpose, it was decided to employ pure cresylic acid for the preliminary work and if optimum conditions for its reduction could be found, to continue the investigation with a low temperature tar. The cresylic acid used was a reddish liquid, completely soluble in caustic soda and boiling completely between 180° and 210°C. The apparatus employed consisted essentially of a catalyst tube of iron 3 feet 6 inches long by $\frac{3}{4}$ inch in diameter, the tube being placed in a vertical position in an electric furnace. The top of the tube was fitted with a rubber cork carrying a calibrated dropping bottle with sight feed and a glass connection leading to a calibrated gasometer containing hydrogen. The base of the tube was connected to a condenser and measuring cylinder and thence to a gasometer for the collection of gaseous products. Each end of the catalyst tube protruded about 4 inches beyond the furnace, these ends being water cooled to protect the rubber joints. Finally a thermo couple was inserted through the cork at the bottom of the catalyst tube so that it registered the temperature at the center of the catalyst.

The catalysts in all cases were carefully deposited on pumice, which was allowed to stand in contact with a solution of the salt for some days to jet thorough impregnation of the carrier.

In operation, the catalyst was brought to a predetermined temperature whilst a slow current of hydrogen was passed through the plant. The cresylic acid was then allowed to enter the tube at a

regulated speed of 30 drops per minute and simultaneously hydrogen was passed in at a measured rate of 1.5 liters per minute. Thus the volumes of all materials entering and leaving the catalyst tube were accurately known. At the conclusion of an experiment the liquid product was shaken with a strong solution of caustic soda and salt and the upper layer of hydrocarbons carefully measured.

The following materials were tested out at 500°, 550° and 600°C. i.e., oxides of chromium, tungsten, molybdenum, vanadium, cerium,

TABLE IX

MOLYBDIC OXIDE ON PUMICE

AVERAGE TEMPERATURE OF CATALYST	LOSS OF LIQUID	HYDROCARBONS ON INPUT CRESOL	GAS IN LITERS PER CC. OF CRESOL		
			In	Out	Difference
°C.	*per cent*	*per cent*			
554	Nil	Nil	0.21	0.24	0.03
605	4	Trace	0.21	0.25	0.04
696	10	18	0.21	0.31	0.10
751	40	38	0.22	0.53	0.31

TABLE X

MANGANOUS OXIDE ON PUMICE

AVERAGE TEMPERATURE OF CATALYST	LOSS OF LIQUID	HYDROCARBONS ON INPUT CRESOL	GAS IN LITERS PER CC. OF CRESOL		
			In	Out	Difference
°C.	*per cent*	*per cent*			
500	12	Trace	0.19	0.21	0.02
564	10	Nil	0.21	0.23	0.02
658	10	3	0.23	0.26	0.03
718	16	17	0.20	0.32	0.12
769	30	40	0.22	0.47	0.25

cobalt, copper and manganese, pentammine cobaltic chloride, lead molybdate, cerium molybdate and molybdenum sulphide; in no case, however, were appreciable yields of hydrocarbons obtained. Accordingly, working with a catalyst consisting of molybdic oxide deposited in pumice, higher temperatures were employed with results shown in Table IX.

The above results show that the desired reaction begins to be manifest at 605°C. is appreciable at 696°C. and considerable at 751°C., the loss of liquid and yield of gas being increased as hydrogenation of the cresol increases in velocity.

The next catalyst used was prepared by impregnating pulverized pumice with a solution of manganous sulphate and igniting the dried material at a red heat to precipitate manganous oxide in the pores of the carrier. The results with this catalyst are shown in Table X.

Manganous oxide and molybdic oxide appear, therefore, to be equally efficient in promoting the conversion of cresol to hydrocarbons.

At this stage, it was decided to try the effect, first of replacing hydrogen by coal gas and secondly of dispensing altogether with a reducing gas. The manganous oxide catalyst was used for the pur-

TABLE XI

MANGANESE OXIDE ON PUMICE

REDUCING GAS USED	AVERAGE TEMPERATURE OF CATALYST	LOSS OF LIQUID	HYDROCARBONS ON INPUT CRESOLS	GAS IN LITERS PER CC. OF CRESOL		
				In	Out	Difference
	°C.	*per cent*	*per cent*			
Hydrogen	750	24	33	0.22	0.43	0.21
Coal gas	752	24	33	0.22	0.43	0.21
Nil (no catalyst)	752	35	35	Nil	0.27	0.27

pose, except when no reducing gas was used, the tube in this case being filled with pumice. The results are given in Table XI.

The above experiments gave the unexpected result that cresylic acid can be reduced substantially to hydrocarbons on simple heating in the vapor phase to 750°C.

Franz Fischer has claimed substantial yields of hydrocarbons by passing a mixture of cresol and hydrogen through a tube packed with tinned iron nails and heated to 750°C. In view of the above experimental results, however, it is clear that hydrogen is unnecessary to effect the required conversion.

RESEARCH IN THE AMERICAN COAL INDUSTRY

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The word "research" has within the past few years become a very popular one in the technical press, and has been applied to many kinds of subjects. Among other definitions, the Century Dictionary describes it as "laborious or continued search after facts or principles" and as investigation. *Encyclopedia Britannica* describes it as "in particular the trained scientific investigation of the principles and facts of any subject, based on original and first-hand study of authorities or experiment," and later says it has a somewhat restricted meaning attached to it in current usage, in the sense that it is applied more particularly to the investigations of those who devote themselves to the study of "pure" as opposed to "applied" science, and to the investigation of causes rather than to practical experiment.

We have in this country a number of organizations splendidly endowed by various philanthropic citizens which liberally encourage research in many scientific lines, most of this work being done along the lines of pure research, and several of our leading manufacturing companies in various lines maintain large laboratories devoted to research work, partly on purely scientific lines but more largely on lines applying more strictly to their own work. In this city we have two splendid public bodies engaged in this work, the U. S. Bureau of Mines, where work is conducted in both pure and applied research, much of it in connection with the coal industry and mining problems, and the Mellon Institute for Industrial Research, where work is always being carried on in many investigations in various useful lines.

Until very recently there was a tendency in our coal industry, and which still persists to a great extent, to regard research as an abstruse matter, which has little or no interest to those managing the industry in helping to solve its problems. This was at least partly caused by the feeling that research was essentially a strictly scientific matter, which would probably increase the knowledge of the subject investigated, but would be of little or no practical advantage. This prejudice undoubtedly arose from the same feeling referred to in the *Encyclopedia Britannica* definition, that the word should preferably be applied to the investigations of those engaged in pure

as opposed to applied science, and from the fact that in some quarters it has been thought that more brains were required for research in pure science than for similar work in applied science, and possibly to the taint that attaches in the minds of some to any contact with money making activities.

In reference to the first feeling, Dr. E. R. Weidlein, Director of the Mellon Institute, in a recent article made the following statement:

"In the past, those devoted to pure research encouraged the impression that pure science, 'a sort of preserve for intellectual sportsmen,' was esoteric and distinctly apart from the ordinary affairs of life, and made no efforts to disclaim the implication that pure scientists necessarily brought to their inquiries a higher and subtler intellect than those who were engaged in applying science to the needs of the community.

"It is certain, however, that, with the recent elaborate development of industrial research and the general recognition of the high quality of work which it demands, this view of the relation of pure and applied science has now disappeared. In fact, while pure science ever has been, and ever must be, the safeguard of industrial research—the wellspring of experience and wisdom—it is generally conceded that the industrial investigator always will be the translator of the language of pure science to the manufacturing world, and in many cases, where necessity arises, the originator as well as the applicator of scientific method. Both pure and applied research are of the same order of importance and each has its own related field."

In answer to the second, so far as the coal industry is concerned, it may be remarked that it has been some years since a great portion of it could be properly charged with being a money making activity. For several years many of the industry's leaders have been urging a greater interest in research work as a help toward solving many of its pressing problems, and a slight beginning has been made in several centers on various problems, but the expenditure made to date has been trifling compared with the amount of work that can be profitably undertaken.

Of what use can research be to the coal industry? If we assume a great interest in the subject by the managers of the large properties, can they hope to obtain from such interest any help in solving their problems that will be worth while, and will repay the time and money required?

The answers to these questions can probably best be made by stating some probelms that have been, or are now being, investigated, and some of the results obtained from this work.

Research of the practical kind has produced the excellent electric lamps now largely used in mine work; an electric gas detector for examining mines, instead of the ordinary flame lamp ordinarily used; the many kinds of gas-proof machines for use where explosive gas is encountered; the short flame, or permissible, explosives, now largely used; a metal for use in pumps, which has greatly reduced the cost of maintenance of such machines; and many other things that have tended to increase the safety, or reduce the cost, of mining.

Research into the composition of coal is being done in nearly all coal producing countries; in Germany it has resulted in the production of oil from coal, a process now reaching the commerical stage, and in that country and in France several other important chemicals have been produced directly from coal; various methods of processing coal for its better utilization as gas and smokeless fuel are now nearing the utilitarian stage; the many by-products obtained in coke making are a familiar example.

A coal research program, to be of interest to the industry at this time, must consist largely of investigation into problems of a practical nature, but with this should be combined pure research into the composition of coal, as many of the practical problems can only be permanently solved by the knowledge of how coal is constituted, and definite knowledge of the physical and chemical characters of our coals will lead to the solution of many pressing problems. The two lines of work should march together, the pure research work in the lead, with the other work playing the secondary (but more important commercially) part of helping the industry forward.

The pure science research on the constitution of coal should determine the physical structure and the chemical compounds that make up the coal substance, how peat is converted into the lowest rank of coal, and how that rank is metamorphosed into higher ones, what are the factors influencing the making of coke; if all of these things were known, the solution of many practical problems involving gas making, spontaneous combustion, smokeless fuels, etc. would be greatly simplified.

The applied research work should determine, for instance, some method of recording the presence of explosive gas in a place, and automatically give warning when it reaches a dangerous limit; some

way of foretelling, or preventing, the occurrence of outbursts of gas; methods of accurately determining the origins of mine explosions; an economical permissible storage battery; a good system of mine lighting; a method of preventing noises from machinery so that roof warnings can be better heard; some way of preventing sulphur getting into mine water, and of cheaply purifying mine drainage; a practical stoker for burning bituminous coal in houses, without smoke; a safe method of burning powdered coal in houses; and many other problems of which any experienced mining man can think.

Much of this work should be done by governmental agencies, such as the Bureau of Mines, working on a well defined program, outlined for at least a five-year period, and with assured governmental appropriations commensurate with the national importance of the coal mining industry; more of it should be financed by the industry itself, aided by individuals interested in the subject. To effect this, the writer suggests the calling of a meeting of those interested to form a Coal Research Board, in which will be represented the various bodies, or individuals, contributing to it, as well as the Bureau of Mines and scientific institutions doing its work, to formulate a program for five years' work, and to secure the necessary funds to carry it out. With the understanding that contributions from coal companies or associations over the period are contingent upon sufficient earnings, that at least 40 per cent of such contributions shall be applied to the pure science research and the remainder to problems in which the contributor is primarily interested, and that the work at first would be done at existing suitable institutions, but later at a central laboratory, to be established when funds are available. It is the writer's belief that sufficient funds for the purpose can be raised. After such a plan is once in effect, the results obtained will certainly secure its continuance indefinitely.

DISCUSSION

CHAIRMAN DAVISON (President, Gulf Refining Company, Pittsburg, Pa.): I want to make a most friendly objection to a statement which Dr. Dunstan made in the presentation of his paper. I know the statement was made on misinformation on his part regarding the American Petroleum Institute. About four years ago President Coolidge made public an official letter in which he expressed great fear with regard to the future supplies of petroleum in America. He did so properly because he was dealing with the question of national defense.

In the letter he appointed what is now known as the Fuel Oil Conservation

Board, of which President-Elect Hoover is a member. Within twenty-four hours after the issuing of the President's letter, the Directors of the American Petroleum Institute appointed a committee to give to the country and the world at large as much information with respect to the question raised by the President's letter as could be had. I had the honor of being a member of that Committee.

You will find in all the libraries in America and foreign countries, the results of the committee's work. It is a volume of several hundred pages and throughout, it gives the assurance that there need be no fear for the supply of petroleum. It is not true that a committee of industry estimated that there was a supply for but fifteen years ahead of us.

DR. DAVID F. SMITH (Bureau of Mines, Pittsburgh): I have been asked to make a few remarks in the discussion of Professor Taylor's paper. Unfortunately, I was not able to read this paper until nine o'clock this morning, and I am afraid my remarks will not at all do justice to this interesting paper.

There are a few things I have though of in connection with the ideas presented in Professor Taylor's paper. In regard to the classification or labeling of catalysts as "hydrogenating," "hydrating," "polymerizing," and so forth, let me emphasize that such a classification should not be made too rigidly. For example, it is well known that a given material may simultaneously possess different catalyzing propensities. Professor Taylor himself, I believe, has suggested that a metallic oxide catalyst may have catalyzing properties due to the metallic element of the catalyst, and also due to the oxygen of it. It is evident that in the case of catalysts having a more complicated composition, one end of the molecule may exhibit one type of catalyzing power while the other end may exhibit another.

Also, there are different types of hydrogenations. The hydrogenation of carbon monoxide to form methane is different in type from the hydrogenation of carbon monoxide to form methanol. Although there are often general similarities in different reactions of hydrogenation, there may also be important differences.

Another very disturbing circumstance, which has been very admirably brought out by Dr. R. E. Burk in his report for the Committee on Contact Catalysis, National Research Council, appearing in the last number of the *Journal of Physical Chemistry*, is that the actual catalyzing substance may be quite different from the substance we are accustomed to regard as the catalyst. For example, the surface of the material which ostensibly is the catalyst, may be covered with a layer of adsorbed material. Since it is only the surface of the material (and, indeed, only certain spots on the surface) which is of importance in catalysis, it is evident that almost, if not quite, undetectable amounts of foreign material may be of the greatest importance, and may even be a substantial part of the catalyzing surface itself, and impart determining catalytic properties to the catalyzing surface.

Another unfortunate circumstance also brought out by Dr. Burk in his report, is that so far no catalytic reaction has been studied quantitatively. This, of course, is not due to any lack of resourcefulness on the part of catalytic investigators, but is due to the inherently complex nature of the problem.

This lack of quantitativeness lies in the fact that in no case of a catalytic reaction has it yet been found possible to measure the actual number of molecules in a position to react. This number is, of course, not in general measured by the partial pressure of the reacting gas, nor is it measured by the total number of adsorbed molecules. It is the number of molecules which are present on only those parts of the surface which are active.

These circumstances, together with the fact that a given sample of catalyst can never (or only with the greatest difficulty) be entirely duplicated in a second preparation of it, have conspired to make fundamental study of catalysis very difficult. These facts have led myself and others to look to the study of homogeneous reaction mechanism, since it is susceptible to simpler and more complete theoretical treatment and since the experimental conditions are more definite and reproducible, for the starting point of the complete fundamental elucidation of all chemical reactions whether homogeneous or heterogeneous.

DR. GUSTAV EGLOFF (Universal Oil Products Company, Chicago): It was pleasing to hear Dr. Dunstan state that he checked some of our experimental results on low temperature tars under cracking conditions, despite the fact that he had used widely different tars than we use for American practice.

Mr. Eavenson's remarks were of interest, but it seems to me that he is relying, or expects to rely, too much upon governmental aid in research in solving the problems of the coal industry. The richness of the coal industry of the past has run into huge sums of money, not alone as investment, but also as profits, and it is high time, in my opinion, that despite the past few disastrous years and these that are coming with the greater competition of oil, and natural gas that they start in with not a million dollars, but at least twenty-five million, and go after fundamental research not alone of scientific, but also of economic value. The industry should gather together the information of the various processes that are struggling now to help the coal industry to come again into the forefront where it should be and where it was some ten or twenty years ago before the competition of oil became acute, by utilizing the best thereof.

To indicate, if not already known, a big country like the United States, with its vast coal fields representing something like 55 per cent of the total world's resources, has no institution founded as such for coal research primarily. I was abroad last summer, and Germany, a relatively small country, has at least three institutions founded largely by the coal industry to carry on research so as to get greater utilization out of its natural resources, whether it be soft coal, brown coal, or hard coal.

Italy has one devoted research from an economic and scientific standpoint, as to better utilization of its coal. England has at least one, and a little country called Czechoslovakia, a year ago founded a coal institution, and headed that institution by Dr. Tropsch, who worked with Dr. Fischer of the Kaiser Wilhelm Coal Institute.

I have no doubt there are other countries with which I am not familiar, that have institutions especially directing all their energies toward the solving of scientific and economic problems in connection with their coal resources. So it seems to me, Mr. Eavenson, that it is up to the coal industry, in view of what

the other countries of the world are doing, to start something, and not look for much governmental aid, because coal is just one part of our industrial life, and if each crippled industry of the United States fled to the government asking it to solve their problems, why the government would be just industry, and industry become government. The coal industry should finance and solve its own technical problems, and, thereby reach its old leadership in our industrial life.

CHAIRMAN DAVISON: The last speaker is evidently a man of great courage. He has made a suggestion to the coal industry which I think requires courage to make, let alone the attempt to secure the money.

The research of coal in the foreign countries of course has been brought about by conditions existing there. The fact is in this country we have had an abundance of oil and coal for many years, and it is only when either of these industries get into financial troubles that there is need of such research as the doctor has mentioned.

Speaking for the oil industry, it is doing great work in research. I might venture to say that perhaps that is one of the reasons exisiting for the trouble in the coal industry. If the coal industry starts this research or investigation that it may cure its ills, then someone will have to come forward and suggest that the oil industry take a fresh hold on research for its protection against the coal business. So we may have a merry time for many years to come switching from one difficulty to another.

DR. W. F. RITTMAN (Carnegie Institute of Technology, Pittsburgh): I would like to ask a question or two. I am wondering whether you made any determinations on the composition of these low boiling consitutents present in your motor fuel, Doctor? I mean those materials which are extremely high in anti-knock qualities. I might say, in that connection, that at the United States Bureau of Mines some three years ago there was a careful analysis made of the gaseous elements resulting from the low temperature distillation of coal, and in a considerable measure we found present much the same type of hydrocarbons as we found in petroleum vapors. Evidently there is a change as we progress from the gaseous hydrocarbons into the liquid hydrocarbons. I don't know of any real work that has been done to determine that, and I am wondering about it.

Another question that I would like to ask is this: in your work on temperature treatment of these heavier oils, to what extent have you studied the time effect? I was particularly interested in Dr. Fischer's paper yesterday, where a matter of relatively few seconds was of the greatest importance in the conversion of methane into benzol. Time factors in the treatment of petroleum hydrocarbons—and there is a relation between petroleum and coal hydrocarbons—is of great importance, as we all know. Where we used to think in terms of heating coils hundreds of feet long, we now think in terms of pipes miles long.

One of the most interesting developments that is going on in the petroleum oil tracking art today is the substitution of pipes for so-called reaction chambers. I don't know where it is going to lead. I don't fully understand it but

it is something that may revolutionize the commercial installations. So I come back to the question of time factor.

DR. A. C. FIELDNER (Bureau of Mines, Washington, D. C.): I would like to discuss all of the excellent papers presented this forenoon, but owing to the lack of time I will limit my discussion to Mr. Eavenson's paper on coal research, a subject near to my heart, and the "motif" of the conference.

There is a very pertinent question as to the agencies for supporting coal research. There is the method we have pursued in ths country of having a Federal Bureau like the Bureau of Mines carry on fuel research, and there is now a trend toward industry carrying on more and more along this line. That is as it should be. It is the duty of the government to initiate research in different industries and bring it to the point where these industries are able and willing to take it over, and then turn their attention to a new field.

Fuels and coal are so fundamental to all of our industries that I believe there still remains a certain amount of research, fundamental research, on coal, its origin, its constitution, and its fundamental properties, which will necessarily have to be done by an organization such as the government, because it comes back to all of the people.

There is a very large field which should receive support. I feel that in the Bureau of Mines we haven't done enough in that field. We have made coal analyses and have published them, but they are limited to analyses. We have not gone into the subject of providing data on the fusing properties of coal, their utilization properties, their gas-making properties, and all the various fundamental factors that enter into the processing of coal. It would be very useful indeed to have a central, unprejudiced agency to make such a survey of our American coals. In other words, that is a broad, public welfare project and one which should have very general support.

These research problems go more and more to utilization for a specific industry. It is a development of processes and so on. It comes more and more into the field which the industry should support itself through coöperative effort. When it comes to an individal process such as some specific problem in low temperature carbonization, it seems to be the logical thing for an individual company to develop this process. Where the companies are in competition, naturally, each company wants to do its own research. When it comes to the fundamental problem that is of interest to all of them, they can pool their interests, and when that same problem is one which is jointly of interest to the coal producer, the coal consumer, and the coal processor, then it becomes a problem of all the people and one in which the government bureaus can coöperate to great advantage.

I feel that all of these agencies can work together and that Mr. Eavenson has presented a view of this problem which is well worth thinking about.

CHAIRMAN DAVISON: Dr. Dunstan, do you wish to make a reply to some of the questions?

DR. DUNSTAN: There are one or two points I would like to refer to briefly. In the first place, I owe you an apology for my apparent misinterpretation of the prophecies of that committee.

I was asked a moment ago why I stopped the discussion of my paper at a point at which it had become interesting, namely, the elimination of catalysis and hydrogenation. The only answer is that is the end of the work so far as it goes. We hope, of course, for further results in the near future. One point I do think should be stressed at this moment, and that is that none of us have yet worked with a true primary time. I am rather looking forward on my return to getting some new material such as Professor Taylor developed, the gasless carbonization of coal, because in all probability he has done something there very much nearer than the stuff I worked with, which was made around 600°C.

Dr. Rittman raised some very interesting points. If you study those low boiling fractions and you make the Bureau of Mines gum test, you get a surprising result. You will find that the gum increases with the anti-knock value. So whatever it is that makes anti-knock that is the stuff that gives you gum. We don't know anything about the nature of the hydrocarbons; it is merely a general observation. We know too little about it to generalize.

As far as the time factor is concerned, of course the reaction at 750 went on exceedingly fast. The matter of seconds were taken up in the reaction, but at lower temperature we certainly found this: that for an increase of 18°F. you approximately double the rate of reaction so at 750 the rate would be very much enhanced.

CHAIRMAN DAVISON: I will call on Mr. Eavenson for his conclusions.

MR. EAVENSON: I must admit at once that Dr. Egloff's idea of the amount of money involved in research is a great deal higher than mine. The entire amount of money that was made by the bituminous coal industry in 1926, all of the companies in the country included, was about $38,000,000. I think the income tax returns for this year will show a considerably less amount than that.

It was not my idea to depend on the government to do this work, excepting that I do think, as Dr. Fieldner brought out, the fundamental part of the work, which is of interest not only to the coal industry but the users also, should be borne by the government.

I think the amount of money that is expended by the government in support of the Bureau of Mines in 1927, as compared with the Department of Agriculture, for instance, is in the magnitude of about 17.5 cents, compared with $1.39 per capita. The total value of mineral products for 1927 was about $5,520,000 as against $12,127,000,000 for agricultural products, a far different ratio from that of expenditures. The Bureau of Mines, through no fault of its own, has been doing less and less of the research work in recent years. Work has been doing dropping off largely because they cannot get appropriations. I think I am correct in saying that their appropriations for coal investigations have not increased even in relation to the inceased cost of doing the work, compared to what they were at the start. The whole point I am trying to bring out is the industry should develop a laboratory of its own, and I think the time is ripe now for doing it.

Comparing the work done abroad with the work done by our American industries, is entirely pertinent, but it is hardly fair in some ways to the American industry. Abroad as a general thing, particularly in Germany, the

coal industry as well as other industries, is encouraged to combine to the greatest possible extent. Any movement in this line in this country is open to indictment by the Federal Government and a strong change of going to jail. It will not apply to research work but does to anything tending to regulate output. For instance, in Germany, the total production of coal on the equivalent coal basis last year was in the neighborhood of 187,000,000 tons. In this country it was about 2.8 times that much. In Germany to produce that coal there were 272 companies and 15 interests produced 57 per cent of the fuel. In this country there were over 6300 mines in 1926, which are the last figures available. There were over 4500 companies and the 15 largest ones would not control over 12 per eent of the industry. So lack of regulation is very largely the result of the unorganized conditions of the industry, which, as I say, is largely due to the fact that there can be no definite organizations without some change in our existing laws, excepting, of course, in research work.

DR. J. C. MORRELL (Universal Oil Products Co., Chicago): Dr. Dunstan stated that generally speaking his results checked those of Dr. Egloff's and mine. He also supplemented his remarks with the statement that you cannot draw generalizations on results from cracking low temperature coal tars. This is certainly a fact because it depends upon the source of the coal tar, the temperature of treatment in carbonizing, the temperature and pressure in cracking, and other factors.

Apropos of that statement, I might contrast some results which we obtained with those which Dr. Dunstan obtained with his particular tar, and the particular conditions under which they were made. For example, in one case he cited that from a low temperature coal tar he obtained 11 gallons of motor fuel. From an average American low temperature coal tar, say, a cross section of the Utah, Indiana, Ohio, West Virginia, and other typical American bituminous coals, we obtained by cracking about 25 per cent of motor fuel based on the coal tar. From a neutral oil obtained from the same coal tar, we obtain about 50 per cent of motor fuel, or motor spirits.

I wish to make a remark on Dr. Rittman's query as to the composition of these cracked motor fuels from low temperture coal tar. He made the statement that coal gas has about the same composition as gas from petroleum. This analogy does not hold for the liquids because in the case of the low temperature coal tar approximately 75 per cent is of an unsaturated and aromatic character, which of course is not the case at all with petroleum or its fractions.

ECONOMICS OF LOW TEMPERATURE COAL TREATMENT

By W. A. Darrah

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Introduction

The views submitted herewith represent principally the writer's opinion as the result of some little study of low temperature distillation, and are submitted with the full knowledge that they are not complete and that some criticism will undoubtedly be justified. If the information here submitted results in a helpful discussion the writer will feel that his efforts have had the desired result.

The coal industry today is largely an industry of a single product which has a single use. The product is of course a fuel and the use is the production of heat. In most climates the demand for heat varies largely with the season, although of course the conversion of heat into power has a stabilizing influence and the conversion of coal into fuel gas (which has industrial application) is another factor adding stability.

In other industries, stability has been obtained by producing a diversified line of materials available for different purposes, and where possible for a different market.

By diversifying the products, and the purposes for which the products are used a composite demand factor may be obtained in most industries. A careful selection of demand factors sometimes results in a substantially constant total composite demand, the lack of which is one of the serious weaknesses of the coal industry as it exists today.

It is the writer's opinion that a widely and properly diversified line of products would not only materially improve the economic stability of the coal industry but would at the same time do much to remove the present labor unrest which appears to be, not the prime cause of the difficulties in the coal industry, but a result of what may be considered lack of economic ingenuity or foresight on the part of the management. The writer feels quite strongly that any bituminous coal producer (assuming a reasonable grade of raw material, sufficient capital, and proper management) can diversify his products and thus do much to increase the stability of his sales, therefore, compensating

in a large part for the seasonal and periodic fluctuations in the coal market.

It evens seems probable that by a careful selection of manufactured products, a given producer could entirely reverse the present load factor on his mine.

The tremendous present tonnage of coal mined requires of course that the products used as a basis for diversification must be ones which will develop large volumes of business, as otherwise the present scale of mining operations would have to be restricted. On this basis there are a number of possibilities which the writer believes are worthy of the serious consideration of coal producers. A few of these are listed at random below.

1. The coal producer may enter the field of power production and sell electric power by acquiring an interest in an existing central station plant, forming alliances with existing distributing companies, or entering the field directly.

2. The coal producer might enter the field of producing and distributing gas either for industrial fuel purposes, domestic purposes or both. The consumption of industrial gas handled by public service companies from large producing plants, is increasing today probably more rapidly then any other single commodity. In spite of this factor, in the writer's opinion, this progress is merely starting, and will continue rapidly to grow. As in the case of the production of electric fuel, the coal producer may acquire an interest in the gas producing companies, may produce the gas for the companies to distribute, or may form some other profitable alliance with the public service companies.

3. The coal producer may enter the field of, or form alliances with, the electro chemical industry, or related operations in which heat or fuel or both are large factors in the total cost of production of the finished product.

4. The coal producer may enter the field of manufacturing finished chemicals such as alcohol, formaldehyde, coal tar products, etc. Those chemicals which offer large markets and which may be produced readily from water gas or producer gas would appear to offer attractive prospects.

5. The coal producer may enter the field of low or high temperature coal distillation with the production resultant by-products.

The discussion which follows is not intended as a brief for the general introduction of any particular low temperature coal distillation process but aims to present some representative data on the economic possibilities of this type of process in general.

The wide cost variations resulting from various geographical locations are so evident that the writer feels that the figures submitted herewith should be considered clearly as approximations and as indicating trends rather than exact conditions. It is of course possible to obtain reasonably accurate figures representing any specific set of conditions.

SUMMARY OF FUNDAMENTS OF LOW TEMPERATURE COAL DISTILLATION

It has of course long been known that when coal is heated certain chemical and physical changes take place with the removal of volatile materials and with a corresponding change in the character of the remaining solid product called coke.

Depending upon the characteristics of the coal under treatment, distillation may begin to be appreciable at temperatures as low as 600° to 800°F. Naturally the higher the temperature of the retort or container in which the coal is placed, the more rapid will be the transfer of heat to the coal, other conditions being equal. Since a rapid transfer of heat means a larger output per unit of time, the first cost of a treating plant is likely to be smaller, as far as the retorts are concerned, when higher temperatures are employed. Therefore the early commercial work in connection with the distillation of coal naturally followed the lines of high temperature application.

It is also true that the quantity and nature of the products resulting from the distillation differ with the temperatures employed, as well as with the nature of the material being treated. It happens that the coke produced in the so-called "high temperature" processes of distillation has been better suited for the average blast furnace use than the coke normally produced by the low temperature process. It also happens that the volume of gas produced by the high temperature distillation process is greater than the volume produced by the low temperature distillation. For these reasons the present industrial development has followed the line of the high temperature process almost exclusively and the distillation of coal at low temperatures while known for many years has only recently received much attention.

Incidentally it is of interest to point out that the distillation of coal by the various low temperature processes and the distillation of oil shale are substantially identical at base, the shale being considered in this case as merely an extremely high ash coal and therefore leaving a residue of no present value while coal when distilled leaves a solid residue of considerable value. Herein is the present economic difficulty with treating oil shales.

Practically all of the present low temperature distillation processes involve the feeding of preferably dry coal into a heating device, and most processes utilize a dry coal of uniform size and with a minimum oxygen content. The essential differences in most of the proposed low temperature processes relate to the means of applying the heat, the method of heat transfer used, and the particular heat cycle to which the material is subjected.

From a thermal standpoint, the greatest efficiency in any process can be obtained by submitting the greatest surface of coal to the heating medium. In some cases this result is obtained by causing hot gases (usually low in oxygen) to pass directly through the coal. In other cases, the coal is agitated or tumbled in a rotating shell or drum. Other processes employ tubes or retorts through which the coal is passed or pressed. As most of the various processes are clearly explained by their various exponents, this discussion will not deal with specific details.

Certain fundaments which appear to be common to all processes are worthy of consideration as they affect the economic side of the matter.

It now seems highly desirable to remove the volatile products of distillation as promptly as possible after they are produced and without subjecting them to further heating. If this precaution is not followed the character of the volatile materials (oils, tars and gas) is materially changed with a considerable loss in market value.

It also appears that for most coals the desired working temperature ranges from 1,000° to 1,200°F. in order to obtain the maximum market value and the maximum quantity of material. Naturally quantity and market value of the volatile material tend to vary in opposite directions since higher temperature normally gives greater volume of gas and sometimes tar, but lower unit market value.

It does not appear that the time to which the coal is subjected to heating makes a serious difference in the nature of the products, providing the coal is uniformly heated for sufficient time. Coal may

be treated in the powdered form or in large lumps, the prime factors being that a much greater time is required to heat a large lump of coal uniformly to the center then is required to heat a small particle of powdered coal. This assumes of course that the maximum temperature to which any portion of the coal is submitted will be the same in both cases.

It follows then from the above principle that small lumps of coal can be heated more rapidly than larger lumps and, therefore, the first cost of the treating equipment would be less in treating finely divided coal than in treating lump coal, other factors being equal.

Unfortunately the coke produced in most processes from the treatment of powdered coal frequently has a materially lower market value than the char produced when larger lumps are used. For this reason it seems that the present trend of development is toward those processes which produce a char in the form of large lumps, although of course the smaller particles may be briquetted when the market price will justify the expense and plant cost.

Description of the Low Temperature Plant

It has been customary in considering the plant equipment necessary for low temperature coal distillation to focus attention almost exclusively upon the actual retort, neglecting to some extent the auxiliary equipment. While this is of course a natural and proper procedure in discussing a new process, it is advisable in arriving at an economic analysis to consider the entire plant equipment, particularly as the "auxiliaries" materially exceed the retort in first cost.

Table I gives a general summary of the estimated detailed cost of a typical 500-ton-per-day distillation plant using retorts of the rotary type. The costs are based on the assumption that the plant is to be constructed on a vacant strip of ground and that the necessary steps must be taken for grading, excavating, building roads, installing piping, foundations, etc. Naturally many of these items could be omitted in case the low temperature plant were installed at a site already having the necessary facilities.

On glancing over Table I it will be noted that the essentials of a coal distillation plant include such items as railroad siding, unloading equipment, elevators, coal bins, coke hoppers, crushers, conveyors and ash handling equipment.

In addition to the above machinery for handling the solid material, it is of course obvious that storage tanks must be provided for

TABLE I

Summary of Equipment Costs (Including Labor and Freight)

500 ton per Day Coal Distillation Plant

Engineering and design	$10,540.00
Foundations, excavation	30,600.00
Foundations, concrete	45,500.00
Grading	7,200.00
Roads	5,400.00
Firebrick, masonry (retorts)	70,800.00
Structural steel	45,600.00
Building masonry	15,800.00
Buildings	60,950.00
Rotary shells	80,000.00
Rolling and driving for shells	50,600.00
Elevators (coke)	12,800.00
Dust collectors	10,250.00
Coal feeders	20,100.00
Coke feeders	15,600.00
Coal hoppers	30,200.00
Unloaders (cars) trestles, etc	20,500.00
Coal handling conveyors, etc	20,450.00
Coal crushers, etc	5,200.00
Coal bins (secondary)	20,050.00
Coke storage and handling	22,100.00
Coal dryers	10,500.00
Elevators (coal handling)	18,500.00
Stokers (12)	30,210.00
Temperature recorders, etc	5,450.00
Tar scrubbers	16,900.00
Tar storage tanks	12,800.00
Tar stills	40,600.00
Tar pumps and motor	8,500.00
Gas exhausters and motor	7,500.00
Railway siding	10,400.00
Gas holders	25,600.00
Gas meters	3,600.00
Gas boosters	8,200.00
Sewers and drains	8,500.00
Water piping	10,000.00
Oil piping and tar piping	15,600.00
Gas piping	12,000.00
Lighting equipment	6,000.00
Wiring conduits, switches	25,600.00
Insulation	20,000.00
General labor, miscellaneous	60,000.00
Supervision, inspection	12,000.00
Testing equipment	15,000.00
Miscellaneous supplies	25,000.00
Briquetting plant	180,200.00
Real estate	20,000.00
	$1,208,900.00

handling tar and oils, and for handling and storing gas. Further, piping must be provided for conducting water, steam, oil, tar, gas, and air to various parts of the plant. Electric circuits and wiring must be included and the necessary pumps and blowers must be provided for handling the gaseous and liquid products. It will be apparent on consideration that except for the retorts the major part of the equipment will be required independently of the type of process employed in the actual distillation. As a rule the proportion of the total investment specifically chargeable to the retorts will range from only one-quarter to a third of the total investment.

As will be discussed later in connection with the nature of the products resulting from the low temperature distillation process, it appears economically necessary to prepare the coke for the market in the form of a relatively large lump, and in the case of many of the low temperature processes, and also when operating on certain grades of coal, it is necessary to include a briquetting plant. This is relatively a large item of expense but does not appear to be avoidable in many cases under present market conditions.

A flow sheet showing the travel of the material through a typical low temperature process plant is shown diagrammatically in Figure 1. The flow of material in the low temperature process requires little discussion as with the exception of the retort most of the operations are practically identical with those operations now being carried on in connection with the high temperature process. It may be noted in this connection that there are at least three general types of retorts being advocated at the present time.

One type consists of a rotary drum with various provisions for heating the coal rapidly, uniformly and at a controlled rate or cycle. This type of equipment is relatively simple and mechanically is quite attractive.

A second type of equipment heats the coal under pressure, as for example in a device somewhat similar to a screw conveyor and serves not only to heat the coal but to agitate it and compress it while being heated. This type of equipment is somewhat complicated mechanically, and therefore may be subject to relatively high maintenance, but in the case of several experimental installations has produced an attractive grade of product.

Another general type of apparatus depends upon heating the coal by subjecting it to contact with a stream of hot gas normally low in oxygen. This type of equipment offers the advantages of rapid,

uniform heating of the material and possibly a high thermal efficiency. Some modifications of this type of process treat the coal in the form of large lumps while other modifications are designed to heat the

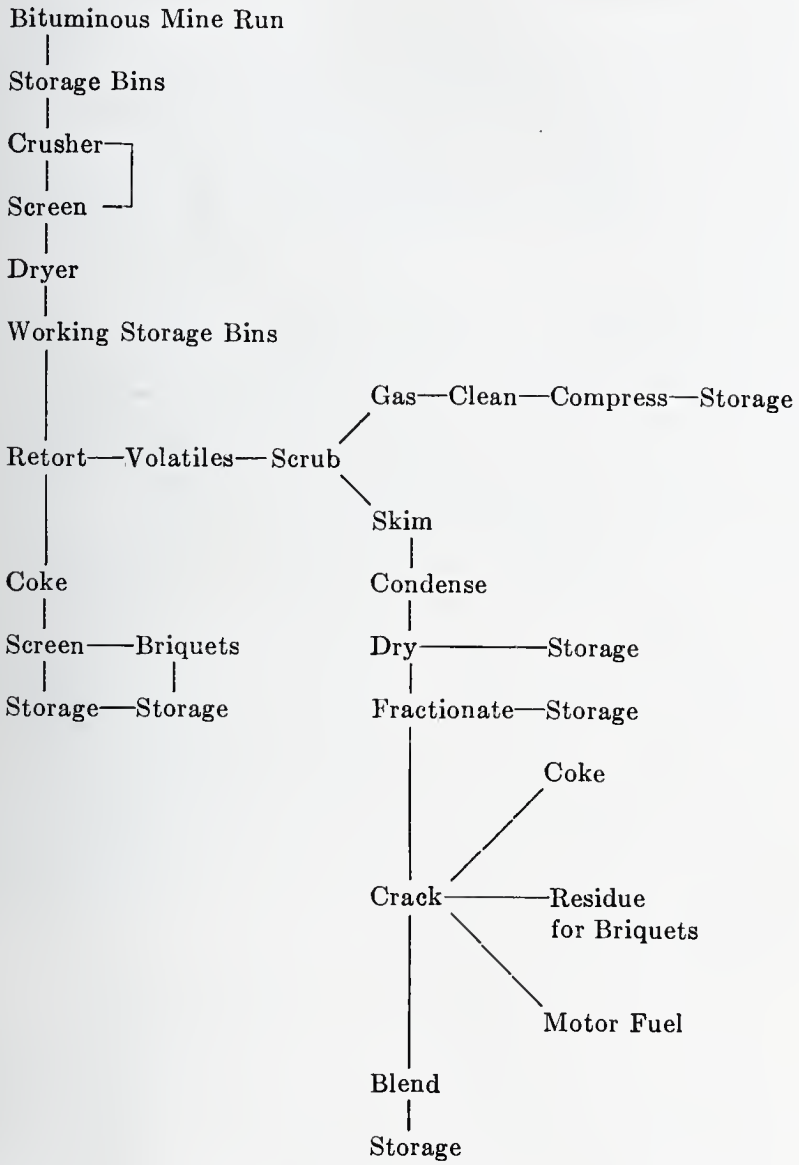

FIG. 1. FLOW SHEET OF LOW TEMPERATURE COAL DISTILLATION

coal in powered form. Advantages may be pointed out for all of these different types of equipment and most of them carry corresponding disadvantages. The method of heating the coal by a moving

stream of gas apparently produces a coke in the form of very small lumps or dust, which reduce its market value for many applications.

Products Resulting from Low Temperature Coal Distillation

Naturally the resulting products of low temperature distillation vary widely both in quality and quantity with the nature of the raw material used, and the heat cycle to which it is submitted.

It is of course desirable as far as possible to use a coal low in ash, low in oxygen content, and high in volatile. For most applications it appears desirable to use a thoroughly matured coal rather than a brown coal.

Coals approaching the characteristics of anthracite offer little advantage in the low temperature distillation process.

The effects of the various factors mentioned above will be more or less apparent to those similar with the characteristics of the distillation process. The higher the volatile material in the coal, the greater will be the volume of by-products, both tar and oil. The more readily the coal distills the greater will be the quantity of liquid by-product and the smaller the quantity of gas, under ordinary conditions.

An appreciable amount of oxygen in the coal serves to prevent the formation of large lumps of coke and tends to produce large quantities of fines in the coke. An excessive amount of oxygen in the coal also tends to reduce the amounts of liquid by-products and to increase the amount of gas. Appreciable amounts of oxygen in the coal also change the character of the liquid by-products and gas. The principal objection to ash in the coal lies in the fact that it accumulates in the coke, making a relatively high ash fuel with a lower market value.

Properties of Low Temperature Coke

One of the outstanding properties of low temperature coke is its so-called reactivity. This term denotes its tendency to combine with oxygen or burn. A low temperature coke has an ignition point frequently 500°F. lower than the ignition temperature of ordinary coke. This property makes low temperature coke a highly desirable domestic fuel, as a fire built from this material is easy to start, maintain, and control. For this reason also low temperature coke is an excellent fuel for water gas plants.

The relatively high reactivity of low temperature coke is probably due in part to the presence of volatile materials not completely removed, and partly to solid hydrocarbons which are "graphitized" in the manufacture of ordinary coke but remain intact in the char.

Low temperature coke may be employed, therefore, to excellent advantage as a domestic fuel and in this field the highest market price may be obtained. The selling price of this material to the ultimate consumer varies widely with the locality and the season of the year. In those cities where smoke ordinances are rigidly enforced, such as many of the cities along the Atlantic seaboard, low temperature coke in compact form is in competition with anthracite or high temperature coke and appears to have decided advantages over either of these products. In this field it may bring close to $10.00 or $12.00 per ton from the ultimate consumer and possibly $8.00 to $10.00 from the retailer, with peak seasonal prices far exceeding these figures.

On the other hand in a district such as the Middle West, where the competition is largely with soft coals, the ultimate market price to the consumer may not exceed $6.00 to $8.00 with a wholesale price in the neighborhood of $5.00. Freight rates naturally have an important effect upon the market price obtainable and in fact the economic success of a low temperature plant depends more directly on the freight rate than on any other single factor. The freight rate may be of decided assistance in raising the selling price of competing products and in other cases freight rates are a serious handicap in increasing the cost of delivering the low temperature coke to the market.

Besides the possibility of selling low temperature coke directly to the domestic trade, it has been proposed to use this product in the form of dust or screenings, as a power fuel under boilers and also as the basis for the manufacture of water gas or producer gas. Low temperature coke is ideally suited for both of these applications, but unfortunately the prices of competitive fuels in these lines are so low that at the present time it does not seem wise to enter this market. Only by obtaining the best prices for all of the by-products produced can the low temperature process be economically justified.

In order to enter the domestic market, low temperature coke must either be briquetted or produced in the form of large, relatively strong lumps. It is quite conceivable that very effective domestic furnaces could be constructed to satisfactorily burn the powered or

granular low temperature char, but owing to the fact that furnaces of this type are not at present in common use, this possibility cannot be capitalized at the present time.

While the cost of briquetting adds a very appreciable sum to the operating cost of the process, it is somewhat doubtful whether or not it will add more than the additional expense incurred in those processes in which briquetting is not required, owing to the direct formation of coke in large lumps. It therefore seems reasonable to include in the operating costs which are outlined on this paper the necessary items for briquetting the coke, and the operating costs involved.

Using typical high volatile coal of a matured bituminous grade, the recovery of low temperature char will range from 50 to 70 per cent per ton of dry coal treated. On this basis of course the ash content of the coke will average about 50 per cent greater than the ash content of the coal employed.

The characteristics of a typical low temperature char are given below in a representative analysis obtained by treating coal in a low temperature rotary drum retort at a temperature of about 1,100°F., total treating time being about two hours.

ANALYSIS OF COKE

Water	1.85 per cent
Volatile matter	6.39 per cent
Fixed carbon	83.32 per cent
Ash	7.94 per cent
Sulphur	0.50 per cent
British thermal units per pound as received	13,670
British thermal units per pound dry	13,927

The coal from which the above coke was obtained had the analysis given below, and was taken from the Eastern Kentucky Field.

Volatile	34.58 per cent
Sulphur	0.59 per cent
British thermal units	14,629

LIQUID BY-PRODUCTS OF LOW TEMPERATURE DISTILLATION

Aside from the solid material obtained in the low temperature distillation process, a very appreciable quantity of liquids may be collected. Naturally the yield of liquid varies with the nature of the coal and the treatment to which it is subjected. Coals which

are ordinarily suitable for low temperature distillation will yield from 25 to 40 gallons of tar per ton of dry coal. The tar as produced is a black sticky liquid giving a distillation test as shown below:

ANALYSIS OF TAR

Water	7.70 per cent
Specific gravity at 60°F	1.118
Distillation—boiling point	93°C.
Distillation at 175°C	2.96 per cent
Distillation at 185°C	3.94 per cent
Distillation at 200°C	14.60 per cent
Distillation at 205°C	17.70 per cent
Distillation at 215°C	23.60 per cent
Distillation at 225°C	27.60 per cent
Distillation at 235°C	31.50 per cent
Distillation at 245°C	33.50 per cent
Distillation at 255°C	35.50 per cent
Distillation at 265°C	37.40 per cent
Distillation at 275°C	39.40 per cent
Distillation at 285°C	42.40 per cent
Distillation at 295°C	44.30 per cent
Distillation at 300°C	45.30 per cent
Distillation at 305°C	47.70 per cent
Distillation at 315°C	49.60 per cent
Distillation at 325°C	51.60 per cent
Distillation at 335°C	53.60 per cent
Distillation at 355°C	59.40 per cent
Residue above 355°C	38.90 per cent
Coke residue	17.62 per cent
Sulphonation residue	1.79 per cent
Tar acids	23.00 per cent

There are many possible uses for tars of this nature, some of which appear to be distinctive and not shared with the tar produced in the high temperature coking process. The tar from a coal low in oxygen contains a considerable quantity of unsaturated hydrocarbons which have some tendency to set or harden when exposed to the air. A portion of the setting appears to be due to oxidation very much in the way that a linseed oil paint will oxidize or harden. There is a possibility, therefore, that the tar may be used as a protective covering or paint, although it appears probable at present that other materials such as oils, may be required in addition in order to produce a marketable grade of paint.

When the tar is distilled out of contact with the atmosphere it

gives a lemon yellow transparent liquid which rapidly darkens on exposure to light or air, in a manner characteristic of the phenols.

The tar may be used as a liquid fuel, of course, and be burned in competition with other liquid fuels, such as petroleum residuals and on this basis the tar has a potential value in the industrial districts, ranging from 3 to 5 cents per gallon.

The tar may be cracked by several of the commercial cracking processes and yields under typical conditions about 25 per cent of its weight in the form of a volatile and readily combustible liquid, which may be used in place of gasoline in motors. Assuming gasoline to have a retail value of twenty cents per gallon, one gallon of low temperature tar on this basis would have a resale value of five cents per gallon, less the cost of processing.

One of the most attractive applications of low temperature tar is in the preserving field as applied to timber. Very large amounts of creosote oil are now imported into the United States largely from European countries The actual amount of preserving creosote oil used in the United States is difficult to determine, but it appears to exceed one hundred million gallons per year and at the present time the market is by no means saturated.

The railroads are today the pioneers in creosoting timber, applying this material to ties, poles, and wooden construction. It seems proven that the application of creosote to ties and similar wood construction will increase the life six to eight fold at least, and in some cases much more. In addition to the railroads many other applications are obviously open to wood preservation, such as building construction, telephone and telegraph lines, transmission lines, etc.

From the analysis given above it will be noted that a typical tar oil contains about 23 per cent of tar acids, which means that by a relatively simple treatment a fairly good grade of preserving creosote can be obtained from the low temperature tar.

It is also of course possible to remove the tar acids by well-known methods and place them on the market in the form of phenol, cresol and related products. In this form, the possibility is opened of producing commercial dyes, intermediates and other products including the well-known bakelite.

The value of commercial creosote ranges from fifteen cents to over twenty-five cents per gallon, depending upon the grade and market conditions. It seems probable that between one-third and one-half of the volume of a typical low temperature tar may be

converted into these products with a potential value ranging from 5 to 8 cents per gallon of tar, less of course the cost of processing.

It would seem logical in any large scale operation to produce a wide range of finished products from the tar, selecting those whose markets are independent and whose demand factors would tend to compensate, for it would be apparent for example that if the motor fuel should be made from tar the maximum demand would probably occur during the summer period, while the maximum demand for coal occurs during the winter period. In the same way most construction work, particularly on railroads, pole lines, and wooden buildings take place during the summer months or at least during a period when the coal demand is a minimum. These two items alone, therefore, offer a possibility of partially compensating for the seasonal demand on the coal mine. Many other possibilities will be apparent. Further, it appears that the demands for the materials which can readily be produced from tar will have a decided tendency to steadily increase in volume, and the markets opened should be relatively stable and strong.

Gaseous Products of Low Temperature Distillation

While the non-condensible residue from the low temperature distillation process contains a considerable number of the higher hydrocarbon gases and therefore offers very interesting possibilities from the standpoint of the manufacturing chemist, it has a direct and rather profitable application in the sale to public utilities companies, for distribution as a fuel gas.

The heat value of the gas will range from 700 to 1,500 B.t.u. per cubic foot, depending primarily on the nature of the coal, the temperature at which the process is carried on, the amount of oxygen in the coal and the dilution of the gases. Under favorable conditions 1,500 B.t.u. gas can readily be obtained and with a typical coal an average production of 3,000 cubic feet of gas per ton may be considered representative. Under practical conditions, it is probable that the value of the gas would be about 1,000 B.t.u. per cubic foot, owing to dilution, dissociation, and other unavoidable conditions. To the writer's knowledge many millions of cubic feet of gas somewhat inferior to that produced by the low temperature process is now being purchased by various public utility companies at prices ranging from 20 to 25 cents per thousand cubic feet, and some over 30 cents per thousand.

Where the gas producer is forced to drive his own bargain with the public utility he has of course only one market and the price which he receives will be controlled accordingly. If, however, the operator of the low temperature plant is in position to control the public utility or to form a working alliance with the utility companies, conditions may be very much more favorable. It is usual for public utilities to sell to the consumer for prices ranging from 60 cents to $1.20 per thousand, the gas which is purchased for 20 to 25 cents per thousand. This is not an unreasonable condition or an exorbitant profit, since this margin includes overhead, interest and depreciation on pipe lines, distribution systems, etc., and all other overhead and operating expenses. The margin mentioned, however, shows the possibilities of profit from the gaseous products of coal distillation. While it is possible to show returns very much larger than 20 cents per thousand cubic feet for the gas if used in the manufacture of other chemicals, it does not seem advisable in this discussion to place reliance on these higher profits.

Under present conditions freight plays very little part in the marketing of gaseous products of coal distillation, the market being limited by the commercial possibilities of pipe line distribution. In this connection it is of interest to note that where large volumes of gas are available over considerable periods, a pipe line a hundred miles long is not considered excessive, as many lines are now in commercial use transporting fuel gas over considerably greater distances, with entire success from an engineering and an economic standpoint.

CONSIDERATIONS IN LOCATING THE PLANT

Considerable time has been spent on discussions regarding the desirability of locating a coal distillation plant at the mine instead of near the market. The factor of availability of labor must also be considered. It is the writer's opinion that under the conditions usually encountered the plant should be located adjacent to the market rather than adjacent to the supply of raw material.

The cost of transporting the liquid and solid products of distillation amounts to nearly twice as much under present freight tariffs as the cost of hauling the raw material; further, the liquid products are slightly more troublesome to handle, involving tank cars. Gas to be transmitted from the mine to the point of consumption would

require a pipe line which means an additional investment which must be carried by the earnings of the plant.

It is also true that in many cases the required grade of labor is more available at the large consuming centers than at the mine, and the characteristics of the labor obtainable near the consumption centers are better suited for plant operations. Further, in locating a plant near a large city it is usually possible to use the output of several mines, if desirable, without materially increasing the freight rate or handling charge. In case the operator has several mines from which to draw his fuel, this is a decided advantage. It therefore seems self evident that large cities offer ordinarily the most desirable markets for the solid, liquid and gaseous products of coal distillation. The somewhat quicker turnover of the manufactured products into cash must not be neglected.

At the present time it appears that the large cities on the Eastern seaboard offer particularly attractive markets for the gas and coke. At the present time the larger markets for the creosote oil appear to be in districts where large quantities of timber are cut rather than along the Atlantic seaboard. If a motor fuel is produced in any quantity from the tar, local markets can be secured at almost any point, although even in this case the Atlantic seaboard probably offers a number of advantages, among which are higher prices, and unlimited demand.

One factor which should be considered in locating the plant is the peculiar tendency of coal from certain seams to oxidize when exposed to the air even for a few hours. The oxidized coal has a very marked effect in many cases on the character of the coke, gas, and tar. The absorption of oxygen by the coal tends to reduce the quantity of large lumps produced in the distillation and also to give a lower grade of tar, of lesser value, and a leaner gas.

COST OF PLANT

The cost of a complete low temperature plant has been discussed previously in this paper. It should be added, however, that the unit cost of the plant will vary markedly with the output. By increasing the capacity of a plant operating on a given process in the ratio of five to one, the first cost of the plant, frequently increases only in a ratio of 3 to 1, or slightly over. The nature of the coal employed has a large effect on the size of the plant and, therefore, its first cost. A coal which permits of successful treatment at 1,000°F. would

require a considerably less expensive plant than one requiring a treatment of 1,200°F. for best results. A dry coal of course requires less equipment than a wet coal, and a coal having coking characteristics will give a better product with less equipment and lower cost in many cases than a so-called "non-coking" coal. A coal which runs largely in the form of screenings or fines, if clean, is well suited for treatment with a minimum investment in plant.

Based on the data at present available, it appears that the average low temperature process is not likely to show a profit when less than 400 tons of coal per day are treated. A plant capable of 500 tons per day would show a reasonable return while a plant with a capacity of a thousand tons of coal per day should be quite profitable.

Operating Costs

The subject of operating costs is a very complicated one as many factors are involved and most of these factors vary with each locality. Any figures submitted must be taken as representing average conditions and subject to some little variation depending on such factors as nature of coal, desired products, geographical location, labor scales, etc.

In the form of analysis submitted herewith, capital charges are included under the general heading of operating costs in an effort to reach a total figure which may be considered as representative.

Tables II, III, and IV give itemized approximate statements of the total operating costs in the case of a rotary drum type of retort, treating respectively 200 tons, 500 tons, and 1,000 tons per twenty-four hour day. The conditions set forth in the comparative tables have been varied slightly to show the possibilities in the low temperature process.

The same tables also show the estimated income which may be balanced against the operating expenses.

The data given in Tables II, III, and IV is intended to be conservative both as to operating cost and income. The tables are prepared on the assumption that the raw material will be slack screenings obtainable at $1.00 per ton at the mine and an additional sum of $1.00 per ton has been allowed for freight. These assumptions naturally are somewhat arbitrary but probably represent typical possible conditions at the present time.

The quantity and character of the by-products used in the tables are those known to be obtained from typical bituminous coals which

TABLE II

THYSSEN LOW TEMPERATURE COAL DISTILLATION PLANT

200 Tons per Day Capacity

Estimated Yearly Operating Expenses

Fixed Capital Charges:			
Insurance and taxes.....	2%		
Interest.....	6%		
Depreciation.....	10%		
Repairs.....	7%		
	25% Fixed capital invested ($535,000)		$133,750
Coal:			
Slack screenings 200 tons per day for 330 days @ $1.00 per ton			66,000
Labor:			
Each Shift			
1 Foreman.....		$8.00	
5 Laborers.....		20.00	
1 Mechanic.....		8.00	
1 Mechanic assistant.....		6.00	
		$42.00	
Three shifts each day for 360 days.....			45,660
Overhead, Labor, Supervision Etc......			10,000
General:			
Supplies, power, etc.....			25,000
Selling Expenses:.....			20,000
Operating costs total.....			$300,410
Freight estimates at $1.00 per ton.....			66,000
Estimated total cost.....			$366,410
Estimated Yearly Income			
Coke:			
120 tons of coke per day for 330 days @ $5.00 per ton.....			$165,000
Tar:			
6000 gallons of tar per day for 330 days @ $0.6 per gallon.....			118,800
Gas:			
800,000 cubic feet gas per day for 330 days @ $.20.....			52,800
Total gross operating income.....			$336,600
Yearly operating loss.....			$29,810

are available in a number of different districts today, when treated by a definite low temperature distillation process under commercial conditions.

TABLE III

THYSSEN LOW TEMPERATURE COAL DISTILLATION PLANT
500 Tons per Twenty-four Hours
Estimated Operating Expenses

Capital Charges:			
Plant Investment		$1,200,000	
Insurance and taxes	2%		
Interest	6%		
Depreciation	10%		
Repairs	7%		
Total	25% Total per year		$300,000
500 tons coal per day, for 330 days @ $1.00 per ton (slack or screenings)			165,000
General:			
Supplies, power, etc			25,000
Labor:			
Three shifts			
1 Foreman		$8.00	
4 Laborers		20.00	
1 Mechanic		8.00	
1 Mechanic assistant		6.00	
Total per shift		$42.00	
Total per day		126.00	
Total per year			41,458
Office help			4,000
Superintendent			4,800
Estimated Total Operating Costs			$540,258
Freight allowed @ $1.00 per ton			165,000
Estimated total cost			705,258
Estimated Operation Income			
300 tons coke per day for 330 days @ $5.00 per ton			$495,000
30 gallons tar per ton coal per 6¢ per gallon for 4,950,000 gallons			285,500
4000 cubic feet gas per ton coal per 20¢ per thousand			132,000
Estimated Gross Income			$912,500
Total cost			705,258
Yearly operating profit			$207,242

TABLE IV

THYSSEN LOW TEMPERATURE COAL DISTILLATION PLANT

Estimated Operating Expenses

1000 Tons per Twenty-four Hours

Capital Charges:			
Plant investment		$2,150,000	
Insurance and taxes	2%		
Interest	6%		
Depreciation	10%		
Repairs	7%		
	25% Total per year		$537,500
1000 tons coal per day, for 330 days @ $1.00 per ton (slack or screenings)			330,000
General			
Supplies, power, etc.			30,000
Labor:			
Three Shifts			
1 Foreman		$8.00	
6 Laborers		30.00	
1 Mechanic		8.00	
2 Mechanic assistants		12.00	
Total per shift		$58.00	
Total per day		174.00	
Total per year			57,420
Office help			5,000
Superintendent			4,800
Estimated Total Operating Costs			964,720
Freight allowed at $1.00 per ton			330,000
Total cost			$1,294,720
Estimated Operating Income			
Total Coke Production:			
600 Tons of coke per day per 330 days: 300 tons @ $3.00			$297,000
300 tons converted into water gas makes 18,000 M cubic feet blue gas per day @ $.10 per M			594,000
30 gallons of oil per ton of coal @ 5¢ per gallon			594,000
4000 cubic feet gas per ton of coal @ 90¢ per 1000 cubic feet			264,000
Estimated Gross Income			$1,749,000
Total cost			1,294,720
Estimated operating profit			$454,280

On comparing the yearly operating expenses with the yearly income, it will be noted that a plant having a capacity of two hundred tons per day shows an annual loss of approximately 6 per cent on the invested capital. In other words on the basis of the tabulation given in Table II, the plant would not earn 6 per cent interest on the investment but would otherwise approximately pay the operating charges as well as allowing a sum for insurance, taxes, depreciation, and repairs.

In Table III, a plant having a capacity of 500 tons of coal per day shows a yearly profit on the investment of about 8 per cent after charging the operating department with 6 per cent interest, and a liberal allowance for insurance, taxes, depreciation, and repairs. In other words a plant of 500 tons per day would earn a total of about 14 per cent on the investment under the conditions outlined. In Table III the yearly operating expense of a plant having a capacity of 1,000 tons per day is exceeded by the yearly operating income by over $400,000. This represents about 20 per cent on the investment in addition to the usual capital charges including interest of 6 per cent, or a net return on the investment of over 25 per cent.

BRIQUETTING THE COKE

It appears obvious that in entering the field of domestic fuels, the coke must be supplied in the form of a strong clean uniform sized lump. This may be accomplished in some processes by an additional extra briquetting operation. The cost of the briquetting operation and the investment for a briquetting unit varies considerably with the nature of the raw material and the process followed. One of the more costly methods, which however gives a satisfactory product is shown with itemized costs in Table V, and summarized in Table VI. These figures are included in order to make clear that this item is one of considerable importance, both from the standpoint of investment and operating cost. One of the large items in the cost of briquetting is the binder. The data given in Tables V and VI assumes the use of a sulphite pitch binder which may probably be considered to be reduced to a commercial basis, but in the writer's opinion is rather too expensive for general application. The residue from the distillation of the low temperature tar may be employed as a binder in case it has not been previously oxidized. The availability of this material naturally varies with the nature of the coal being

treated and the process. Another commercial binder which appears to be well suited for this application is the residuum from the cracking of petroleum. Geographical location will naturally have an im-

TABLE V

ESTIMATED COST OF MANUFACTURING BRIQUETS

Basis of Operation:		
Production of briquets per hour 12 tons, per day of 24 hours 288 tons, per year of 365 days 105,120 tons, about 77% efficiency equals 80,000 tons of briquets per year.		
Estimated Investment	$150,000	
(1) *Depreciation,* 7½% of $150,000		$11,250.00
(2) *Material for Repairs and Maintenance,* 5% of $150,000		7,500.00
(3) *Binder* 10% of 80,000 tons, 8,000 tons @ $18 per ton		144,000.00
(4) *Power, Steam, Fuel and Supplies,*		
500,000 K. W. Hours @ 1¢	$5,000.00	
12000/M lbs. of steam @ 25¢	3,000.00	
2800 tons coal for baking oven @ $2.50	7,000.00	
Lubricating, waste, cleaning	1,000.00	
(5) *Labor:*		16,000.00
Per Shift of 8 Hours:		
1 Foreman @ $1.00 per hour	$8.00	
1 Man at pulverizer and preheater @ 60¢ per hour	4.80	
1 Man at binder and mixers @ 75¢	6.00	
1 Man at press @ 75¢ per hour	6.00	
1 Man at baking oven @ 75¢ per hour	6.00	
1 Man at cooling table and briquet bin @ 60¢	4.80	
1 Spare man @ 50¢ per hour	4.00	
	$39.60	
833 Operating shifts		
83 Overhauling, delays and repairs shifts		
916 shifts @ $39.60		$36,274.00
(6) *Miscellaneous*		
City taxes 1% of $150,000	$1,500.00	
Fire insurance 2% of $150,000	3,000.00	
Contingencies	2,400.00	
		$6,900.00

portant part in determining the type of binder employed, as a small difference in freight rates may easily exert more influence in selecting the proper type of binder than abstract engineering considerations.

PATENTS

A consideration of the economics of low temperature coal distillation would not be complete without a passing reference to the patent situation. The general processes employed have been shown and described in the literature and in many issued patents covering a period of over fifty years.

In spite of this fact many of the processes now being urged differ in detail from early disclosures, and as a result there are hundreds of issued patents and undoubtedly many more pending patent applications covering various phases of this industry.

TABLE VI

SUMMARIZED COST OF MANUFACTURING BRIQUETS

	ITEM	PER YEAR	PER TON OF BRIQUETS
1	Depreciation	$11,250.00	$0.141
2	Material for repairs	7,500.00	0.094
3	Binder	144,000.00	1.800
4	Power, steam, fuel and supplies	16,000.00	0.200
5	Labor	36,274.00	0.453
6	Miscellaneous	6,900.00	0.086
		$221,924.00	$2.774
	Cost of manufacturing briquets per ton		$2.774

At the present time it is rather difficult to say what process, if any, is clear of infringement of other patents, or which process may be completely controlled by patents in the hands of its exponents. It should be emphasized, however, that before embarking in extensive investments, this phase of the matter should be thoroughly investigated both from the standpoint of offense and defense.

CONCLUSION

If conclusions are justified from the rather general discussion here given, they would appear to be as follows:

1. The coal mining industry of today is suffering, among other things, from lack of stability in part due to lack of diversity of products and markets.

2. By ingenuity of the management in the manufacture of products

other than crude fuel from coal, the industry will gain materially in stability.

3. Many fields are open, as described above, and the field of low temperature distillation offers attractive possibilities. The low temperature distillation process makes available a wide field of products including a high grade domestic fuel, a source of gas for industrial or domestic use, and a considerable group of chemical products.

4. The low temperature process is mainly attractive when carried out in connection with a working alliance between a coal producer and a public utility, or other marketing organization.

5. The low temperature process requires a considerable investment in plant and a large daily output in order to reach an economical successful basis.

6. The low temperature distillation process is not a fully developed industry but one which offers much promise to the coal operator willing to invest time, effort, and capital in both the engineering and economic side, and to use ingenuity in developing markets.

APPENDIX

For completeness I am attaching some interesting operating data submitted by Mr. M. J. McQuade on the Hayes Process, and a discussion by Mr. Robert M. Crawford dealing broadly with the economics of Low Temperature Distillation.

TABLE VII

ESTIMATED RESULTS* TO BE OBTAINED FROM THE OPERATION OF A HAYES PROCESS LOW TEMPERATURE COAL CARBONIZATION PLANT LOCATED AT MOUNDSVILLE, WEST VIRGINIA. CARBONIZING 200 TONS OF SLACK PER DAY

	COST	
	Per day	Per ton
Labor cost	$90.00	$0.45
200 tons of slack at $1.10 per ton	220.00	1.10
Royalty 200 tons at 30 cents per ton	60.00	.30
Repairs and supplies	50.00	.25
Power and water	16.00	.08
Office expense	12.00	.06
Total cost	$448.00	$2.24

* Figures submitted by courtesy of Mr. M. J. McQuade of the Coal Carbonization Company.

Income per Day

150 tons of briquets at $5.00 per ton at the plant		$750.00
10 gallons of light oil (distillate) per ton or 2000 gallons per day at 10 cents		200.00
2000 cubic feet of gas per ton for sale or 400,000 cubic feet at 25 cents		100.00
Gross income per day		$1,050.00
Less cost of operation		448.00
Gross earnings per day		$602.00
Gross earnings per year (300 days)		$180,600.00
7 per cent per annum on the investment ($360,000.00)	$25,200.00	
10 per cent per annum for depreciation	36,000.00	61,200.00
Net Profit per annum		$119,400.00

The above figures are based on using the pitch residue of the tar distillate for binder for the briquets and using a sufficient quantity of the gas for heating the retorts.

REPORT OF ENGINEERS OF THE ALLIS-CHALMERS MANUFACTURING COMPANY OF MILWAUKEE, WISCONSIN, OF TESTS MADE AT THE LOW TEMPERATURE COAL CARBONIZATION PLANT OF WEST VIRGINIA SUPER FUEL COMPANY, MOUNDSVILLE, WEST VIRGINIA. THE TESTS WERE MADE OVER A PERIOD OF TEN DAYS AND TEN NIGHTS (FEBRUARY 9 TO 19, 1928) OPERATING THREE RETORTS

Copy of Report

*Average Results of Tests**

Total operating hours	229 hours
Total retort hours	687 hours
Total through put of slack	218.24 tons
Total slack through put per retort hour	635 pounds
Total slack through put per retort in 24 hours	7.6 tons
Total tar oil recovered	5,834.6 gallons
Total average tar oil recovery per ton of slack	26.7 gallons
Total quality of gas, average	819 B.t.u.
Total quantity of gas, average per ton of slack	6,000 cubic feet
Total briquets per ton of slack	1,500 pounds
Total tar oil distillate light oil per ton of slack	10.68 gallons
Total pitch per ton of slack	160 pounds
Total benzole per ton of slack	2 gallons

* Figures submitted by courtesy of Mr. M. J. McQuade of the Coal Carbonization Company.

DISCUSSIONS SUBMITTED BY MR. ROBERT M. CRAWFORD

It is presumed that the reader of this discussion is generally familiar with the subject of Low Temperature Carbonization.

As a basis for this discussion it is of value to consider the following simple balance sheet based upon one ton of high volatile coal.

Costs:

Coal @ $4.00/ton	$4.00
Conversion cost, fixed charges, profit, etc.	See below

Returns:

Coke @ $5.00/ton—67 per cent yield (net)	$3.35
Gas @ 36 cents/M.—4M cubic feet (750 B.t.u.)	1.44
Tar @ 6 cents/gallons—28 gallon	1.68
Motor fuel @ 20 cents/gallon—3 gallons	0.60
	$7.07
Less cost of coal	4.00
Balance available for conversion cost, fixed charges, profit, etc.	$3.07

The figure of $3.07 can conveniently be split 3 ways as follows:

Conversion cost	$1.09
Fixed charges	.98
Profit	1.00
	$3.07

The above figure for conversion cost is generally accepted—the profit appears fair and reasonable. As to fixed charges it appears safe to allow for:

Depreciation	20 per cent
Interest	6 per cent
Taxes and insurance	2 per cent
Contingencies	2 per cent
Total	30 per cent

We have, then, $0.98 representing our fixed charges of 30 per cent which, translated into a more useful figure, gives $3.27/ton coal/yr. or about $1200/Ton/da. as the *maximum* amount of money that can be invested in plant.

It is interesting, now, to consider that the cost of a Low Temperature Plant *exclusive of the carbonizing retort only* would be somewhat as follows:

Coal preparation and handling	$286/T./da.
Coke handling	134/T./da.
By-product plant	200/T./da.
Light oil and motor fuel	180/T./da.
	$800/T./da.
Balance available for retort only	400/T./da.
Total	$1200/T./da.

We are talking now about *selling prices* of plants and not *cost prices*. The literature is cluttered with figures of "plant costs" varying from $800/T./da. to $1000/T./da. but obviously such figures are not tenable in a consideration where plants are to be sold since they represent "cost prices."

The auxiliary equipment necessary at a carbonizing plant aside *from the RETORT ONLY* would be the same regardless of the type of retort, hence the writer prefers to consider LOW TEMPERATURE PROCESSES on a basis of *Retort Cost Only,* since this is the determining factor. Having arrived, then, at a point of this discussion, the writer contends that any Low Temperature Retort, to be successful, must be installed at a *retort cost* not to exceed $400/T./da. We cannot conclude otherwise until Low Temperature Carbonization has demonstrated its ability to show conclusively greater enhanced values of the by-products.

LOW TEMPERATURE CARBONIZATION OF COAL BY THE HAYES PROCESS

By James Balph

Secretary, Coal Carbonization Company, Pittsburgh

AND

M. J. McQuade

President, Ben Franklin Coal Company of West Virginia, Pittsburgh

Read by James Balph

The thought has occurred to me that before I read this paper it would be only proper for me to give a short explanation, because the question would naturally arise in your minds as to why one who is not a technical coal man, not an engineer, not a chemist, and not having any special knowledge of the coal industry or rather of coal especially, should be called upon to read a paper of this kind before an audience composed, as this largely is, of eminent chemists, engineers and technical men from all parts of the civilized world.

In the first place I was assigned this duty because of my being the Secretary of the company that has built a coal carbonization plant and now has it in actual operation, and while I am not an expert in coal, I have had experience over a number of years on the financial side of the coal business, and that has qualified me to speak, I think, with a little authority on one phase of the coal question.

It is my little experience in that line that I wanted to call to your attention, because I know there are a number of operators in the audience and I think that it will be interesting to them and possibly of some interest to the technical gentlemen who are with us.

In 1916 I was induced in a moment of temporary weakness to purchase an interest in a coal property in West Virginia. During the years 1917 to 1921 I was highly pleased with my investment; those were the flourishing days of the coal business in the United States and I began to form the opinion, nay I had the conceit to think that I was a shrewd investor, but after 1921 I quickly changed my opinion and from that time down to this my estimate of my sagacity as an investor in coal properties has steadily diminished with the price of coal. I was fortunate in one thing, however. I had as a partner a gentleman who had had years of experience in the uses of coal from

the standpoint of a practical coal operator and producer. That gentleman is Mr. McQuade who has just been introduced to you.

He for a number of years was a member of the research committee of the United States Coal Organization, and I think he knows the coal business thoroughly, on all sides, in all departments.

Immediately after the glorious times from 1917 to 1921, when they had become only a pleasant memory, we found that we had to do something at our plant or the manner in which we were getting results from it would result in our losing the plant. We were not only making no money but were losing very rapidly.

Our coal property is located at Moundsville, West Virginia, about eighty miles from the city of Pittsburgh. Our coal is what is known as the Pittsburgh No. 8 vein. It is highly volatile and soft and in producing our coal we produced about 40 per cent slack. So slack is our problem. We could not get a price for it, and as every coal operator knows, unless you can get 75 cents, which is about the price of slack now, you will soon have to shut up shop if you are producing 40 per cent slack from your mine.

That was our proposition and that was the problem which confronted us. We made up our mind that we must in some way find a method of putting slack into such form that it could be sold on the market at a profit, and we turned our attention to the solution of that problem. For two years we searched up and down the country and investigated until at last it was our good fortune to meet with Mr. Charles Hayes, an engineer, chemist and inventor, a citizen of the United States, but at that time residing in Paris, France, who had been giving a number of years of time and attention to the study of low carbonization of coal.

He represented to us that he had invented or discovered a process by which coal could be carbonized by a cheap installation at a low cost and at a profit. We investigated his claims thoroughly and we satisfied ourselves that the basic principles of his invention or discovery were correct, and we thereupon undertook and had conducted a number of tests on a small scale that satisfied ourselves that if we built a plant we would at least not lose the money that was put in it and that it could be operated and it would do what he claimed for it.

So in 1927, about a year and a half ago, we built a plant adjoining our coal properties at Moundsville, and it has a capacity for the treatment of fifty tons of coal per day. We operated that plant

successfully during last winter, sold our product at a profit, and we built this summer a second unit of a capacity of fifty tons of coal per day, and that is now in operation, and we claim is operating at a profit.

That has been our experience. I do not know anything about the technique of coal, but I do know dollars and cents pretty well and I know that we are producing our slack and selling it in this form at a decided profit. We are taking our slack, passing it through the retorts by this process and in twenty-five minutes we can convert it into a briquetted form of fuel, and the product we take from that as we pass it through consists of about thirty gallons of oil to the ton of coal and about 3500 cubic feet of 800 British thermal unit gas in addition to selling our briquettes at a profit.

That has been our experience and now I will read the paper describing that process.

The primary objectives to be attained from the distillation of coal at low temperature are as follows:

First: To make possible the production of a suitable domestic fuel from our high volatile bituminous coals. This product to be of a character that ignites readily, lends itself to ease of control during combustion, to burn smokelessly or nearly so, and to be in such marketable form as to withstand handling with the least degradation.

Second: To obtain the low volatile solid residue in a form that is highly combustible on boiler grates or in which it is a dry, easily pulverized product, which may be readily prepared for pulverized fuel firing.

Third: The recovery of a large yield of tar oil of such characteristics that have the highest market value.

Fourth: To make possible the production of either a high or low quantity yield of gas, to suit the requirements of the marketing conditions at point of plant location.

Fundamentally low temperature carbonization is a problem of heat transfer and to make any process commercially profitable, this must be accelerated to the greatest degree. The process should be such as to be applicable to the distillation of a wide range of coals of both the non-coking and coking class, and be flexible in its adjustments to operation on coals of varying characteristics; it must be of the continuous automatic operation type, or as nearly so, as possible, to obtain a minimum of labor cost.

Initial investment cost per ton-day input of coal is necessarily an

important factor as to the commercial possibilities, as also are the maintenance and replacement costs.

Having these objectives and fundamental features in view as necessary in the development of a suitable apparatus the Hayes Process has been brought to a stage where commercial success is assured.

An initial unit was constructed at Moundsville, West Virginia, about one year ago by the West Virginia Super Fuel Co. This unit has a rated capacity of 50 tons of coal input per twenty-four hours.

The purpose of this plant was to produce a domestic fuel from the slack coal, the slack first being carbonized at low temperature and the solid product being put in briquetted form for the market.

This unit has been in commercial operation to date and the product has met with favor in all localities where it has been introduced.

A second carbonizing retort of a rated capacity of 50 tons per day, in which some features of a later development are embodied, has been added to this plant and is now in operation.

In describing the latter carbonizing unit it may be classed as an externally heated, horizontal, rotating cylinder type, operating continuously and in which a positive means for the propulsion of the coal through the retorts is incorporated.

Seven retorts are embodied in a battery type of furnace. Each retort is heated within individual heating chambers, and the operation of one retort unit is in no way dependent upon the other six.

Two such batteries of seven retorts each, located alongside each other, are considered as an operating unit, both being supplied with coal from a single hopper and the char being handled through a quenching conveyor and discharger common to both.

The nominal input coal capacity of such a unit is 100 tons of coal per twenty-four hours a day, 50 tons to each battery, this varying to a certain extent upon the character of coal processed and the character of resulting products made.

Retorts are made of a special alloy metal, 17 inches inside diameter, $\frac{3}{4}$-inch wall thickness and 20 feet long, being supported on rollers located at both ends, outside the furnace walls. The speed of rotation is one and one-half revolutions per minute. Gasketed connections are made to stationary feed end and discharge end heads, located at either end of the retorts.

A specially constructed screw type of conveyor having a progressive oscillating motion, gives positive propulsion to the coal

Fig. 1

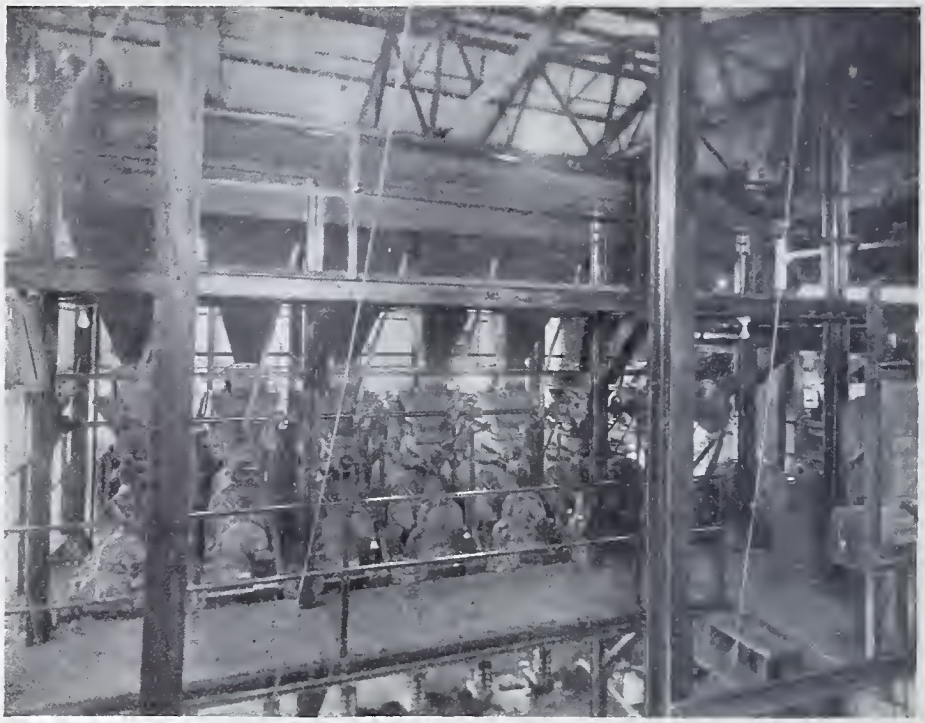

Fig. 2

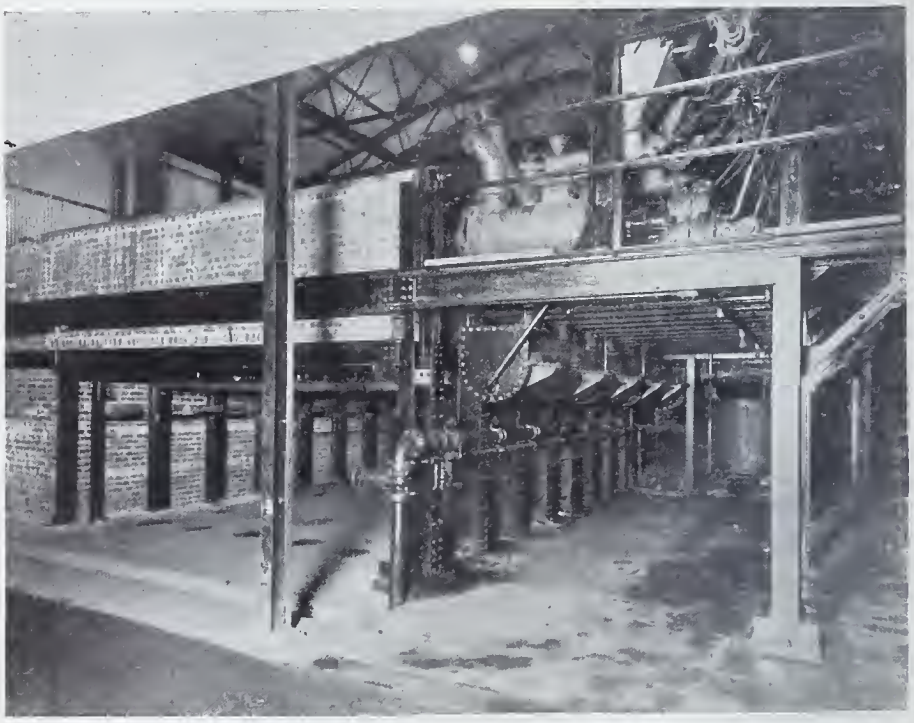

Fig. 3

within the retort. The motion of the screw is such that in the foward oscillation the coal is at first propelled toward the discharge end of the retort a given distance, and then on the reverse oscillation it is returned a distance slightly less than the forward movement. Due to this means of forward and back propulsion of the coal, a total theoretical travel of 240 feet is made in twenty-five minutes by each particle of coal in passing through the length of the retort. Independent geared units give motion to the screws and rotate the retorts, all seven of which are driven from one main line shaft, each having a clutch engagement with this driving medium to give the independent operation to each.

The furnace which is built of fire brick and well insulated comprises seven individual heating chambers, each having a removable top cover. Each chamber is heated by means of six gas burners located on the under side and spaced so as to give direct heating to three-fourths the length of the retort. Each burner has an individual combustion chamber connecting with the heating chamber, thus providing temperature regulation at any point throughout the length of the retort. This insures flexibility in the control of the furnace temperatures, thus making it possible to produce either high gas yield with the consequent lower tar yield, or vice versa. Burners are supplied with air and gas from manifold pipes, and are controlled by valves individually or from master valves controlling the total number of burners for each heating chamber. The furnace is supported by structural steel columns and framework at sufficient height from the ground level to allow for access to all burner valves, etc. Waste gases from heating chambers are directed downward through individual flues which are dampered to a main flue leading to stack.

Superheater coils are located in the waste gas flues, their purpose being to reclaim a portion of the waste heat and by the injection of the superheated steam thus made into the retorts, eliminate to a great degree the cracking of the tar vapors into gas and thereby prevent the possible formation of carbon on the inner walls of the retorts.

The coal gas, tar vapors and steam generated within the retort is withdrawn from the coal feed end, through offtake pipes connecting with one collecting foul main, and thence through standard condensing and gas washing equipment. Tar oil is collected in settling tanks, where separation from water takes place and thence is pumped

to the main storage tank. Coal gas is stored in a gas holder, from which the fuel gas for furnace heating is supplied.

Coal is fed to retorts continuously by means of a screw feeder which is supplied from a hopper bin located directly over the feed end of the retorts and supported upon the furnace structural frame. The coal is fed at a uniform quantity speed, which is such as to give a theoretical depth of not more than three inches of coal throughout the length of the retort. Thus due to the thinness of the layer of coal, the agitation of the mass due to the oscillation of the retort screw, and the particles of coal coming in contact with the entire interior circumference of the retort due to the rotation of this member, makes heat transfer to be rapidly effected.

The solid product, termed char, is discharged from each of the retorts into a main collecting screw conveyor which runs the entire length of the furnace setting, thence being discharged into the quenching conveyor where it is cooled by water sprays at the end of which is a rotating discharge unit, which directs the char onto an open belt conveyor, being conveyed by this means to a grinder for reducing it to the fineness required for the briquetting operation.

In this installation the gas produced by the carbonizing operation is used as a fuel for the retort-heating furnaces and that in excess to this requirement is used for steam raising. However, it is contemplated to use producer gas as a heating medium when future expansion in plant capacity will be such as to warrant the installation of such apparatus. The gas produced in the carbonizing operation will then be available for marketing and due to its high calorific value will find a ready market, thus making an additional revenue to the plant operation.

The coal processed is the slack produced by the Ben Franklin Coal Company at Moundsville, West Virginia, being the $\frac{3}{4}$-inch screenings, the average analysis of which is as follows:

Per cent moisture	2.25
Per cent volatile	39.40
Per cent fixed carbon	51.04
Per cent ash	7.31
	100.00
B.t.u. value	13,500.00

A rescreening of the slack over a $\frac{1}{2}$-inch bar screen is done at the carbonizing plant and the coarser sizes are reduced by grinding to pass through a screen of the same size.

The coal in this form permits of complete carbonization and means only the crushing of about 50 per cent of the raw coal as received from the mine. Thus the advantage of using mine slack, which not only reduces the amount of crushing necessary to put it in a form to be properly carbonized, but gives the opportunity of using a mine product which now has a very low market value as compared with the mine run coal.

The average yield in products from a ton (2000 pounds) of this coal is as follows:

Char (12 per cent volatile)	1,326 pounds
Tar	30 gallons
Light oil	2.1 gallons
Gas (800 B.t.u. value)	5,000 cubic feet

The char or solid product contains less than one per cent of moisture and is light and friable in character which is readily crushed in preparation for briquetting or for pulverized fuel firing. A typical analysis made on a dry basis is as follows:

Volatile	12.00 per cent
Fixed carbon	77.00 per cent
Ash	11.00 per cent
	100.00
B.t.u. value	13,100.00

Tar as withdrawn from main storage tank contains about 1.5 per cent of moisture. The free carbon content, insoluble in benzol averages normally less than 2 per cent. Specific gravity varies as to the temperature used in processing. Results obtained from the standard retort distillation tests (A.S.T.M.-D-20-26) water free basis, are as follows:

Per cent to 170°C	5.3	specific gravity 0.860
Per cent to 235°C	15.2	specific gravity 0.948
Per cent to 270°C	9.7	specific gravity 1.003
Per cent to 300°C	13.4	specific gravity 1.043
Per cent of pitch remaining	57.2	

Light oil recovery from the gas by scrubbing methods averages two gallons per ton of coal processed, has a specific gravity of 0.780

at 60°F. It contains cyclic saturated and unsaturated hydrocarbons which make it valuable as a motor fuel.

The gas produced has a calorific value of approximately 800 B.t.u.

A still will be installed at the plant for the fractionating of the crude tar into light, medium and heavy oil, which is marketed as such. The pitch remainder being used as a binder for the briquetting of the char.

The briquettes, which are pillow shaped, weighing approximately 2½ ounces each, are being formed in Belgium type rolls, after which they are air dried with the result that they are in a form that will stand the handling through shipment and delivery to the consumers' bins with little degradation.

The briquettes burn with little or no smoke and retain their form until entirely consumed. Combustion is readily controlled and they burn without forming clinker.

Slack coal, which is produced in the bituminous coal mining industry, constitutes 20 to 40 per cent of the output of the average mine; and as the market value of this product is, in most cases, lower than the mining cost, it is in most cases a deciding factor as to whether a property may be operated at a profit or a loss. The conversion of this grade of coal to a higher form value by means of low temperature carbonization, presents an opportunity for realizing a just return for the fuel value of the screenings. The solid and liquid products are in such a form as to be readily transported to the market; and economies realizable from locating of a plant directly upon the mine property make this industry especially inviting to the bituminous coal mine operator.

Located in municipalities, the process may be operated in conjunction with the present city gas plants, in which case, furnaces would be fired with producer gas, thus the char gas produced is available for use as an enriching medium for uncarburetted water gas,effecting a saving of the value of the oil now used for carburetting.

Recent tests have shown marked advantages for the use of low temperature char in pulverized form for large power-plant use, and presents a means of obtaining a cheaper fuel for the raising of steam if the value of the tar and gas be credited to the plant operation.

I wish to say a word in closing and that is this: it was my privilege to attend the last session of this body, and if I remember correctly I heard some speaker from this platform say that the commercially

successful low temperature distillation of coal is just around the corner. In our experience and in our humble judgment we earnestly and sincerely believe that it is not around the corner: it is here.

DISCUSSION

MR. W. L. AFFELDER (V. P. Hillman Coal & Coke Company, Pittsburgh, Pa.): I would like to ask about what a fifty ton unit would cost.

MR. F. L. TENNEY: You are speaking of the furnaces themselves or the furnace with the auxiliary?

MR. W. L. AFFELDER: The complete plant, the original unit and the second.

MR. F. L. TENNEY: Of course, the cost of the auxiliary equipment exceeds the carbonization plant itself due to the fact that it is not advisable to put in equipment, such as the coal handling equipment, for only fifty tons a day; therefore we had to put in large equipment. The retort setting itself I should say would cost $50,000. That is the actual cost of the ones we put in. The auxiliary equipment would cost in the neighborhood of $150,000. This auxiliary equipment, however, is in some cases large enough for a 500-ton plant and will be used as such when the plant is enlarged.

MR. W. L. AFFELDER: I understood you to say that the retorting equipment for a fifty ton unit would cost about $50,000 and the auxiliary equipment $150,000, and that the auxiliary equipment is capable of handling more than fifty tons.

MR. F. L. TENNEY: In some cases the apparatus is large enough to handle 200-ton plant, and in others as high as 500. It is better to give the figures possible in a larger plant.

MR. W. P. PUTNAM (The Detroit Testing Laboratory, Detroit, Mich.): I would like to ask the speaker, if it is permissible, if the type of seals used in the retort is the stuffing box type or is it some special design?

MR. F. L. TENNEY: Do you mean the packing around the rotating retort?

MR. W. P. PUTNAM: Yes.

MR. F. L. TENNEY: It is ordinary high temperature packing, graphite and copper wire.

MR. W. L. AFFELDER: I would like to ask if I am correct in assuming that the plant at Moundsville cost about $250,000; that is twice $50,000 plus $150,000.

MR. F. L. TENNEY: Yes, on the two retorts plus the auxiliary equipment including briquetting.

MR. THEODORE G. WEBER (Central Union Gas Company, New York City): What is the carbonizing temperature in the retorts?

MR. F. L. TENNEY: We carry our maximum temperature between 1,500 and 1,600 in the furnaces. Our highest is at the feed end to drive out the moisture of course, tapering down towards the discharger.

MR. C. F. LENTZ (New Jersey Zinc Company, Palmerton, Pa.): What is the highest temperature it will stand? Will it go higher than 1,500?

MR. F. L. TENNEY: This is a special alloy that is developed for our purpose and will stand up to 2,100 degrees.

MR. C. F. LENTZ: Is it cast?

MR. F. L. TENNEY: It is nickel alloy chromium.

MR. C. S. CROUSE (University of Kentucky, Lexington, Ky.): Did I understand you to say that you heat it with steam?

MR. F. L. TENNEY: Yes, we interject some superheated steam inside of the retort.

MR. C. S. CROUSE: Have you any information on the difference of the quality of the product with and without steam?

MR. F. L. TENNEY: I have not investigated. Our main object in that, of course, is to reclaim some of the heat from the flue gasses, and we really believe that it eliminates the carbon from our retorts because we have had no trouble with that since we have been using the steam.

MR. C. S. CROUSE: Have you found any difference in the saturation and unsaturation of your tar? I was asked to see how it worked out and that is what I am driving at.

MR. F. L. TENNEY: You are getting into the chemical field now and I am a mechanical engineer on the job, so I could not say exactly.

MR. C. F. LENTZ: Do you make it in other forms?

MR. F. L. TENNEY: Yes, this metal could be used for other purposes. It is not a product when purchased.

MR. C. F. LENTZ: Will you give me the cost or approximate cost? Is it very expensive?

MR. F. L. TENNEY: It runs according to the size of the casting. I believe these cost in the neighborhood of 40 cents per pound.

MR. W. L. AFFELDER: In Mr. Balph's paper he mentioned that 5,000 feet of gas of about 600 British t.u. is recovered. Is that the total amount of gas or is that the amount of surplus gas in addition to what is used in retorting?

MR. F. L. TENNEY: I will have to make a correction; that was 800 British thermal units.

MR. W. L. AFFELDER: Five thousand feet of eight hundred British thermal units.

MR. F. L. TENNEY: That is the total gas. That is of course, as we are operating at present.

MR. W. L. AFFELDER: About what per cent of this gas is necessary in the carbonizing?

MR. F. L. TENNEY: About 50 per cent is used in the carbonizing.

MR. W. L. AFFELDER: The other 50 per cent could be used for exterior use?

MR. F. L. TENNEY: Yes, for steam raising and for distillation of the charge. We, of course, have not made any arrangement for the sale of that gas although that would be possible in some localities.

MR. MARSHALL JOHN H. JONES (Bertha Commerce Company, Pittsburgh, Pa.): What is the tar yield per ton?

MR. F. L. TENNEY: About 30 gallons. The scrubbing of the gas is roundly two gallons to the ton.

MR. JAMES DICKSON (British Columbia Government, Victoria, B. C.): What is the average development of the carbonizing chamber?

MR. F. L. TENNEY: Theoretically it is about 3.5 inches deep at the highest point.

MR. THEODORE G. WEBER: Have you any idea of the life of these retorts?

MR. F. L. TENNEY: We investigated that material very thoroughly and found retorts which had operated over a period of six years under very similar conditions, and that is our best knowledge.

MR. THEODORE G. WEBER: Is that six years of continuous operation?

MR. F. L. TENNEY: It is six years of continuous operation.

MR. G. M. S. TAIT (Consulting Engineer, Washington, D. C.): Is any quenching done to the coke?

MR. F. L. TENNEY: The coke is quenched with water.

MR. JAMES DICKSON: Has any difficulty been experienced in the coal passing through the retort?

MR. F. L. TENNEY: Do you mean sticking to the interior of the retort?

MR. JAMES DICKSON: Yes.

MR. F. L. TENNEY: None at all.

MR. NEWELL G. ALFORD (A. N. Eavenson & Associates, Pittsburgh, Pa.): What is the melting point of the tar that you use in winter?

MR. F. L. TENNEY: 180 to 185.

MR. W. L. AFFELDER: What disposition do you make of your tar? Do you do any refining or do you sell it as crude tar?

MR. F. L. TENNEY: At present we are selling it as crude tar.

MR. W. L. AFFELDER: Do you get any better price for low temperature tar than for high temperature?

MR. F. L. TENNEY: I am not familiar with the high temperature industry.

MR. W. L. AFFELDER: What is this tar worth per gallon?

MR. F. L. TENNEY: The crude tar?

MR. W. L. AFFELDER: Yes.

MR. F. L. TENNEY: It ranges from 5 cents to 6 cents.

MR. MARSHALL JOHN H. JONES: What is the labor cost per ton?

MR. F. L. TENNEY: That I will answer on a basis of a 300-ton plant, which is more favorable of course. Based on the information we have from the operation of that plant, it would be about 50 cents.

CHAIRMAN MORROW: Do you mean 50 cents per ton of coal?

MR. F. L. TENNEY: Yes, per ton of coal.

MODERN DEVELOPMENTS IN LIGNITE CARBONIZATION

By Dr. F. P. Kerschbaum

Technical Advisor of Metallbank und Metallurgische Gesellschaft, Frankfurt a. M., Germany

In the following I would like to report on modern developments in lignite and brown-coal carbonization in Europe, especially Germany, in order to indicate that such carbonized coal is going to be a complement of or even a competitor to bituminous coal in different parts of the world, and may lead to the building up of new regions and branches of industry.

In the first place some statistical figures. According to the International Geological Congress held at Toronto in 1913 the world's available resources of fossil fuel were estimated to amount to 7.2 billion tons (7.2×10^{12} tons). Of this amount nearly 3.0 billion tons (2.99×10^{12} tons), equal to some 40 per cent (in tons) (41.5 per cent) were classified as class D, this class comprising what you term here sub-bituminous coal and lignite, and we in Germany "Braunkohle." For the sake of brevity, when speaking of sub-bituminous coal, I wish to denote all coal belonging to this class D, comprising sub-bituminous coal, brown-coal, lignite, etc.

By continents, the distribution of these 3 billion tons of sub-bituminous coal is given in Table I. From this table you will see that the bulk of resources, about 94 per cent, is found here in America, while Europe has the small share of about 1 per cent only, of which about 90 per cent is found in Central Europe, Germany, and the territory of the former Austrian-Hungarian Empire.

Another instructive figure is the ratio of sub-bituminous coal deposits to total coal deposits in the chief countries. These figures are, calculated in tons: United States of America, 57 per cent; Canada, 79 per cent; Europe, 5 per cent, or calculated in calorific value—equalling 3 tons of sub-bituminous coal to 1 ton bituminous coal: United States of America, 30.5 per cent; Canada, 55.5 per cent, and Europe, 7 per cent.

Therefore, speaking about resources, America has the absolute preponderance in sub-bituminous coal deposits in the world and is even richer in such coal deposits, compared with bituminous coal, than any other country in the world.

But now about production. The figures are given in Table II. It appears that the percentage figures for production are reverse to those of resources: Central Europe holding about 94 per cent, of production, America only a few per cent. You see, sub-bituminous coal production is practically a European problem and Germany,

TABLE I

THE WORLD'S AVAILABLE RESOURCES OF SUB-BITUMINOUS COAL, BROWN-COAL AND LIGNITE

	TONS	PER CENT
America	$2,811,906 \times 10^6$	93.8*
Asia	$111,851 \times 10^6$	3.73
Europe	$36,682 \times 10^6$	1.22†
Oceania	$36,270 \times 10^6$	1.21
Africa	$1,054 \times 10^6$	0.03
Totals	$2,997,763 \times 10^6$	100.00

* About 68 per cent, United States of America; about 32 per cent, Canada.
† About 90 per cent, Central Europe.

TABLE II

THE WORLD'S PRODUCTION OF SUB-BITUMINOUS COAL, BROWN-COAL AND LIGNITE

	1913 IN TONS	PER CENT	1923 IN TONS	PER CENT
Central Europe	$118,825 \times 10^3$	95.2	$143,412 \times 10^3$	94.5
Germany	$87,233 \times 10^3$	70.0	$118,249 \times 10^3$*	78.0
Rest of Europe	$5,250 \times 10^3$	4.1	$3,609 \times 10^3$	2.4
United States of America	470×10^3	0.38	$1,687 \times 10^3$	1.1
Canada	193×10^3	0.15	$2,800 \times 10^3$	1.9
Rest of World	250×10^3	0.2	200×10^3	0.1
Totals	$124,988 \times 10^3$		$151,708 \times 10^3$	

* 1925:$139,792 \times 10^3$ tons; 1927:$150,503 \times 10^3$ tons.

together with the former territory of the Austrian-Hungarian Empire, is the classic country of "Braunkohle" industry.

There are two reasons to account for the large German brown-coal production. Firstly: the density of population, this being about ten times higher in Germany's brown-coal districts than in United States of America's North Dakota, and 100 to 200 times higher than

in Canada's Saskatchewan. Secondly: accessibility. In Germany the overburden is small, the seam undisturbed. An overburden of 10 (−20) meters is high, followed by a seam of 20 (−80) meters thickness; therefore open-cast mining is the rule, 80 per cent of the German brown-coal being produced in this way. You will find a view of a typical modern German open-cast mine in Figure 1, showing the modern device of a conveyor-bridge.

Here in America, especially in North Dakota, the overburden is in general about 20 or 30 meters, the thickness of seam about 6 to 8 meters.

Of this large German brown-coal production—equaling almost exactly in tons the German bituminous coal production—at present,

FIG. 1. CONVEYOR BRIDGE

nearly half is burnt as raw coal, the other half being briquetted. This briquetting process would be a very satisfactory general solution for the utilization of brown-coal, if briquetting would not require a certain colloidal structure of the coal, only to be found in Germany and to a certain extent in Australia, but nowhere else.

Therefore a more universal solution of the problem of making use of sub-bituminous coal deposits was needed. It was found in carbonization. Owing to the fact that coking or carbonization methods for bituminous coal could not be applied to sub-bituminous coal—the raw materials and products being altogether different—carbonization of brown-coal had to develop in its own way in Germany, independent of the process of coking bituminous coal.

The first step in the carbonization of German brown-coal was achieved by producing tar out of earthy (Sapropel) coal, in order to get paraffin wax. Later on the value of the coke obtained was realized. The "Rolle" furnace type was used for carbonization purposes for many decades. A diagram of a Rolle furnace is given in Figure 2. You see a vertical cylindrical furnace built from fire-

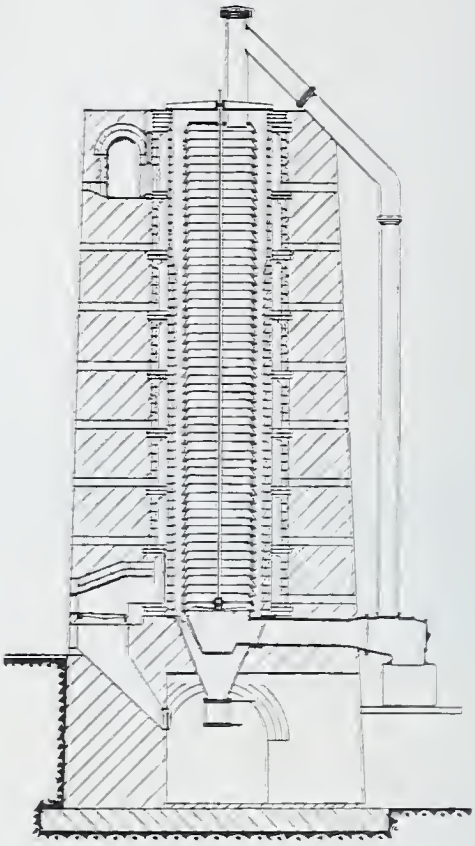

FIG. 2. CARBONIZER "ROLLE" SYSTEM
Capacity, 3–5 t/24 h raw brown coal

brick material. Crushed raw brown-coal, containing 40 to 50 per cent water and 5 to 15 per cent tar, is heated up to about 700 to 800°C. In this furnace the coal forms an annular layer, 3 to 4 inches thick, of about 5 feet internal diameter and 35 feet in height. This annular layer is indirectly heated from the outside through the firebrick wall, the inside wall forming a lattice of conically shaped cast-iron rings, 50 to 60 in number. Thus the evaporation of the moisture and the

carbonization are both performed in this furnace, yielding only a small throughput of coal, 4 to 5 tons per furnace and day. Tar and gases are drawn off from the hollow interior. The tar is condensed, giving a yield of not more than 50 to 55 per cent of the theoretical value; the gas developed is used for the heating of the furnace. At present (1926) about 1000 furnaces of this type are still in operation, producing about 80,000 tons tar and $\frac{1}{2}$ million (444,000) tons coke per annum, working up the small share of 1 per cent (1.5×10^6 tons) of the German brown-coal production.

Numerous efforts have been made to increase the efficiency of the Rolle furnace, especially regarding throughput. Mostly in vain. There is only one successful new type of furnace based upon the principles underlying the Rolle furnace, the Geissen furnace, Figure 3, a carbonizing machine of the dimension of a Rolle furnace, built from special cast iron, heated internally. It is specially designed to work up earthy German brown-coal. About 20 such furnaces, working up 60 tons pre-dried brown-coal per unit and day have been erected in Germany; nowhere else up to now.

However, in order to work up all the different varieties of sub-bituminous coal—different in respect to physical and chemical behavior—from raw coal of lignite structure up to sub- and even semi-bituminous coal, a more general solution of the problem of carbonization was required. This solution has been derived from producer gas practice in German raw brown-coal and briquets. As a by-product of producer gas, tar was obtained. During the years 1914–1918 great efforts were made in Germany to get tar, i.e., oil, from abundant national resources, i.e., brown-coal. Of all the different methods tried to work up raw brown-coal none succeeded. Finally a solution was found in the working up of briquets. In a big gas producer type the briquets are carbonized in the upper part by the hot producer gas current itself; a pretty high yield of tar is obtained. Some 20 furnaces were erected according to this scheme, chiefly at the "Dea" Plant, Rositz, 50-ton units. The gas produced is consumed in the adjoining briquet factories.

The situation was developed thus far, when in 1921 another group of German engineers took up the problem of carbonization of Braunkohle and—as far as I can see—succeeded in establishing a rather general system of carbonization, now known as the "Lurgi Process." In Figure 4 a diagram is given.

The principles, on which the Lurgi process was based were defined as follows:

From a general point of view

a. Re raw material: Any sort of fuel—only non-caking—should be worked up, without any pre-treatment, except for coal dust.

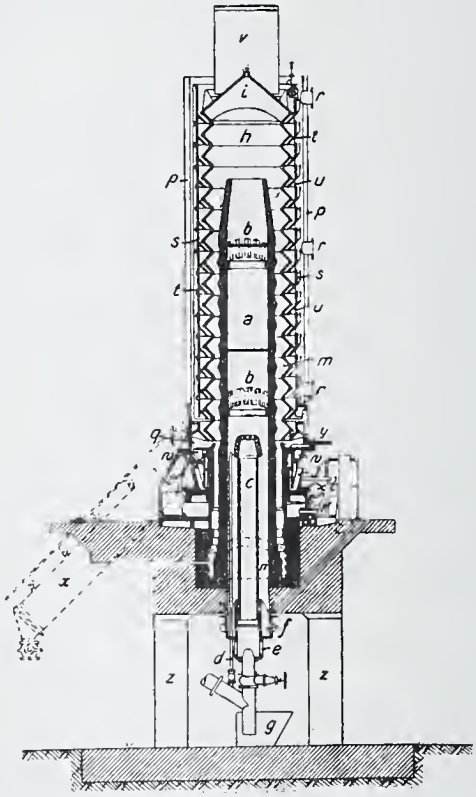

FIG. 3. CARBONIZER "GEISSEN" SYSTEM
Capacity, 100 t/24 h raw brown coal

b. Re end products: Coke should be obtained of highest possible calorific value and reactivity, preserving as far as possible the structure of the original fuel. Tar should be obtained with high yield, without cracking and without dust. No gas.

From a physical-chemical point of view

a. All heating up of the fuel should be done directly—for heat economy—and slowly, to avoid disintegration, using hot gas currents passing through the coal (rinsing gas system).

b. Hot gas and fuel should be led in counter current, avoiding cracking and condensation of tar.

c. The zones of drying and carbonizing of the coal and cooling of the coke should be clearly separated.

d. Carbonization temperatures of 500°C. and above, up to 1000°C.,

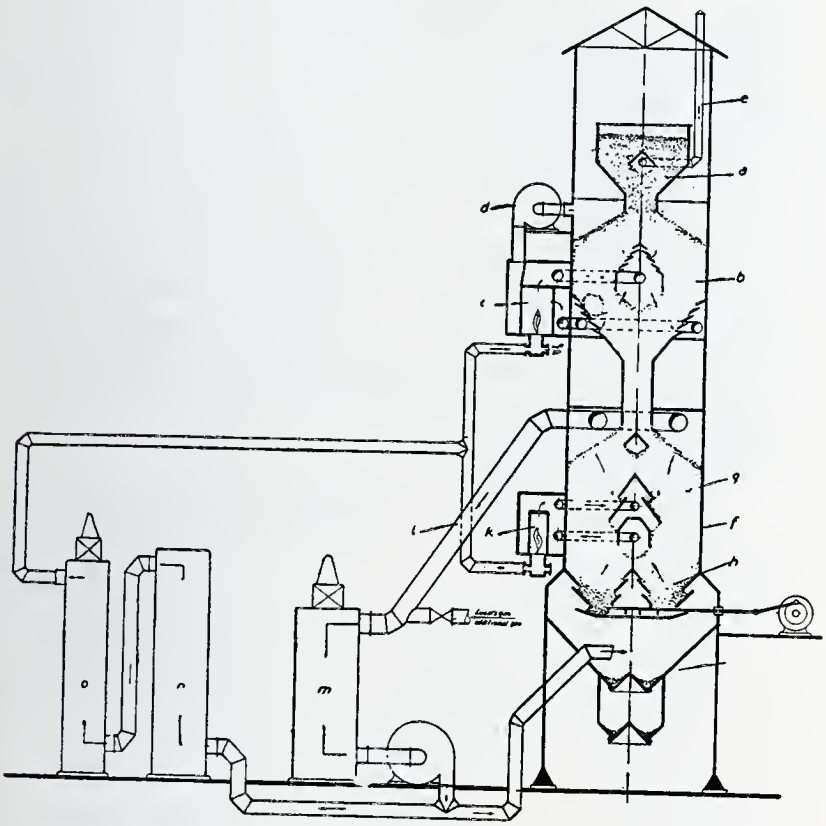

FIG. 4. DIAGRAM OF THE "LURGI" CARBONIZING PROCESS

a, lignite-bin; *b*, pre-dryer; *c*, furnace; *d*, exhauster; *e*, waste gas; *f*, carbonizer; *g*, distilling zone; *h*, cooling zone; *i*, discharger; *k*, furnace; *l*, distilling gas; *m*, electric separator; *n*, cooler; *o*, washer.

should be applicable, without using material of iron construction, exposed to high temperatures.

From an engineering point of view

a. Big units giving 100- to 200-tons throughput per day should be developed.

b. The whole three-step process should be entirely continuous.

c. For the carbonization operation the vertical shaft furnace should be used, the interior built entirely from firebrick material according to old coke oven practice.

d. All heating up of the gas current should be done outside the drying and carbonizing system.

e. There should be no movable parts in this whole furnace, except coal (under gravity) and gases (by blowers).

f. The most simple, compact construction should be achieved, insuring the greatest heat economy.

The diagram indicates the method of operation.

The fuel (raw brown-coal) in pieces up to 4 to 5 inches, is charged into the bin on top of the pre-dryer by a special charging car, insuring uniform and continuous charging. From this moment the fuel travels down entirely automatically without any intermediate mechanical transport device. The bin feeds the fuel into the pre-dryer, where the drying gases are driven through the layers formed of the fuel in two stages. Drying is effected down to 0 to 4 per cent moisture, but care is taken not to carbonize.

From the pre-dryer the fuel travels down further through a hose system into the big one-stage carbonizer, its lower part serving as a cooling chamber for the coke. After cooling, the fuel is taken out by a sliding table device. If the content of moisture of the fuel is less than 36 to 38 per cent, no auxiliary source of heat (additional producer gas) is required. If it is higher, say 48 per cent, 6 to 8 per cent of the fuel carbonized have to be gasified in an ordinary auxiliary gas producer and this gas added to the circulating gas current.

At equilibrium conditions the gases act as follows: The gas coming from the carbonizer, containing the tar, is led through the electric Cottrell Tar Condenser through a blower and afterwards divided into two parts. The one part, the cooling gas current is led back to the bottom of the carbonizing tower, the other part of the gas current is passed through a direct or indirect cooler to a washer for light oil; from there it is fed into two burners, heating up the circulating gas currents exhausted from the carbonizing and drying zone.

For the carbonizing operation itself only a small amount of heat is required to make up for radiation losses, carbonization itself being a slightly exothermic reaction. The gas of the carbonizing zone is kept at a calorific value of about 1200 to 1400 Cal/m^3, if necessary by addition of auxiliary producer gas. The carbonizing gases enter

at 500 to 550°C. and are drawn off at 200°C. The chief amount of heat is required in the drying zone. The gases enter at 250° and leave at 85 to 90°C., a few degrees above dew point. The pre-dryer

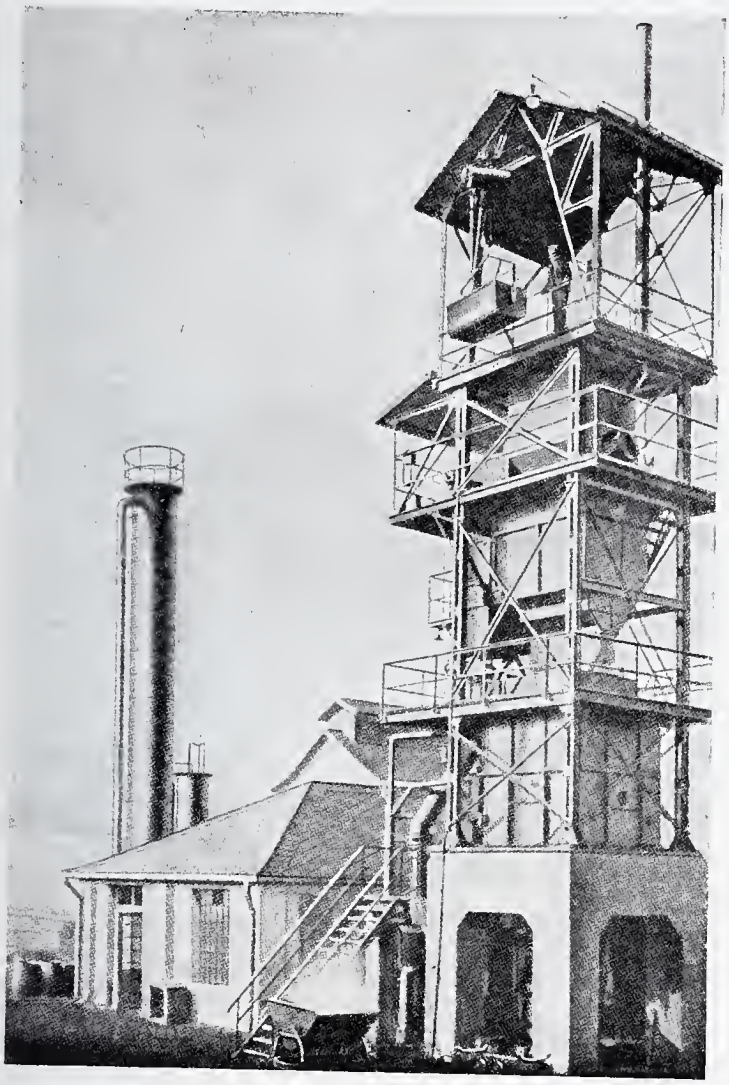

FIG. 5. "LURGI" CARBONIZER
Capacity, 25 t lignite/24 h

gas is a mixture of combustion gas and circulating gas. It contains 50% water vapor and not more than 0.3% O_2. The surplus gas, carrying off the water vapor, escapes through the chimney (outlet).

Plants of this type are in working operation in the following countries:

1. Greece. 25 (+50)t.
2. Hungary, Figure 5, 25 t./day plant.
3. Germany, Figure 6, 120 t./day plant.
4. England.

There are under construction:

In the United States of America, where a 160-ton plant in North Dakota has just been completed. Figure 7 under construction.

FIG. 6. "LURGI" CARBONIZER
Capacity, 120 t lignite/24 h

In Canada, at Bienfait, Saskatchewan, a 350-ton plant, Figures 8 and 9.

The raw materials and the different types of coke produced are shown in the following figures:

Figures 10 and 11 show a typical German raw brown-coal and the carbonization product. Figures 12 and 13 show North Dakota raw lignite and the coke obtained. You will notice that quite a marked disintegration of this fuel takes place. The destruction occurs practically entirely in the pre-dryer, not in the carbonizing zone. In

Fig. 7. "Lurgi" Carbonizer
Under construction

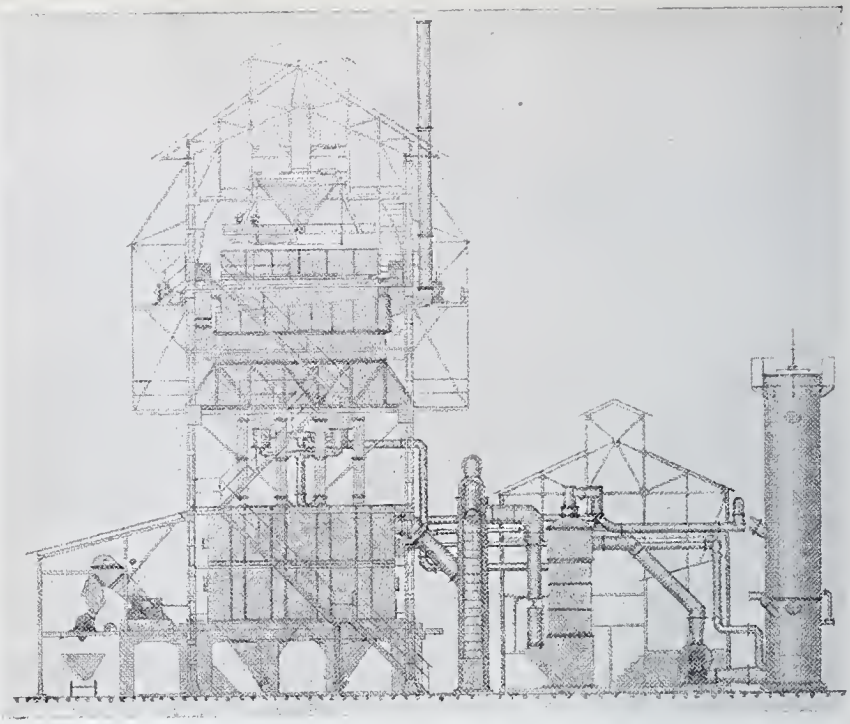

Fig. 8. "Lurgi" Carbonization Plant
Capacity, 350 t lignite/24 h

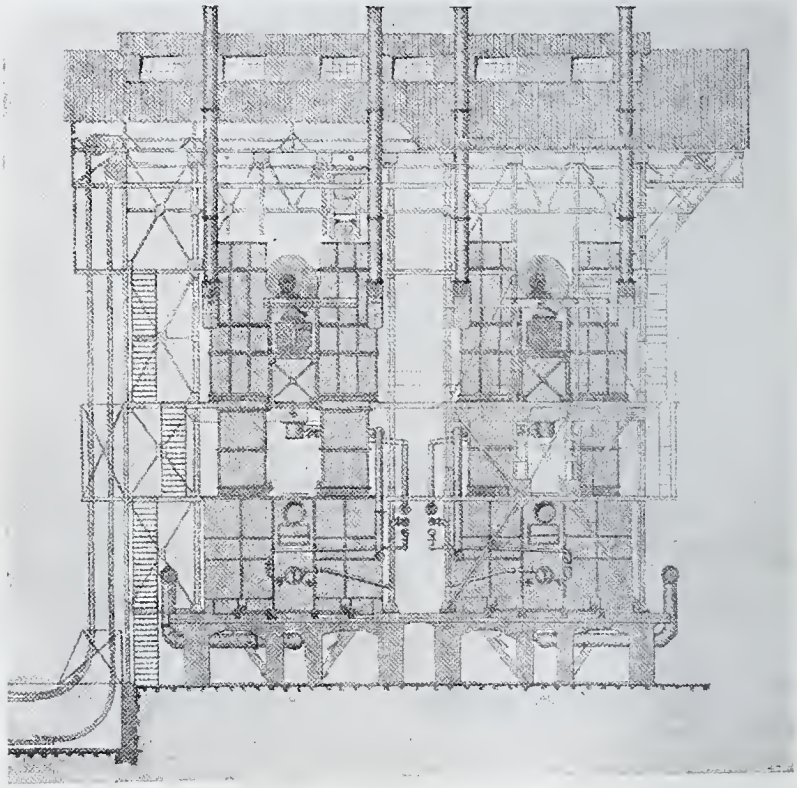

Fig. 9. "Lurgi" Carbonization Plant
Capacity, 350 t lignite/24 h

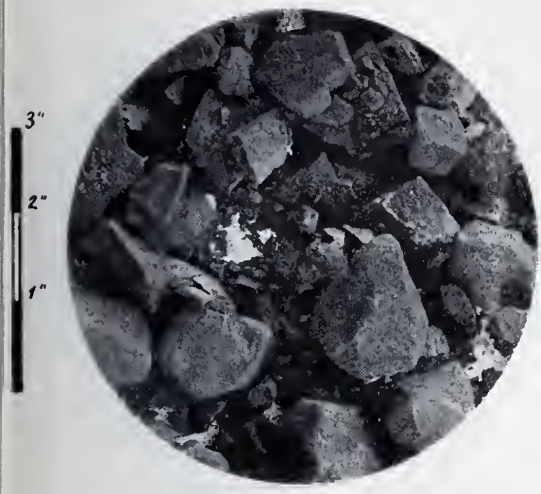

Fig. 10. German Raw Brown Coal

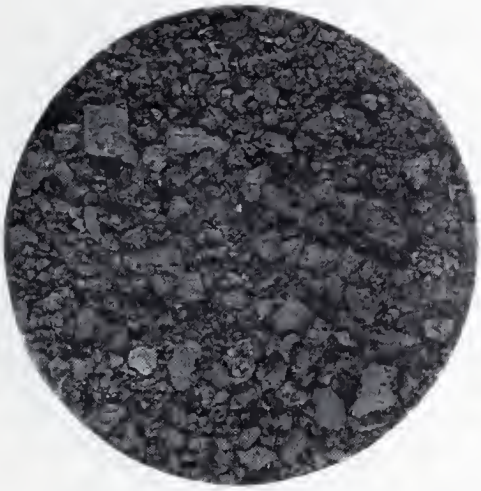

Fig. 11. Semi-coke from German Raw Brown Coal

Fig. 12. Lignite of North Dakota (United States of America)

Fig. 13. Semi-coke from Lignite (North Dakota)

FIG. 14. SEMI-COKE OF XYLITE (GREECE)

FIG. 15. SEMI-COKE OF SUB-BITUMINOUS COAL (SPAIN)

FIG. 16. SEMI-COKE OF CANNEL COAL (ENGLAND)

FIG. 17. SEMI-COKE OF LOW GRADE BITUMINOUS COAL (UTAH)

spite of this disintegration the direct process works successfully, owing to the fact that it has been achieved to lead the fuel uniformly through the furnace and to pass the gas current through the whole material. There are other kinds of sub-bituminous coal, which after carbonization show a semi-coke of practically the same structure as the raw material. It is not surprising that Greek lignite (Xylite),

TABLE III

CARBONIZATION RESULTS

RAW MATERIAL	ROLLE PROCESS	LURGI PROCESS	
	German brown-coal	German brown-coal	North Dakota lignite
Moisture:	∾50.0%	45.0%	31.6%
A1 retort analysis: H_2O.....	∾55.0%	49.6%	39.7%
Tar.....	∾ 8.0%	8.7%	4.7%
Coke....	∾28.0%	30.8%	46.0%
Gas + loss....	9.0%	11.9%	9.6%
	100.0%	100.0%	100.0%
Calorific value (lower).....	2,400 Cal./kgm.	3,000 Cal./kgm.	3,600 Cal./kgm.
Throughput/d.....	4–5 t	120–130 t	160–175 t
Coke produced:			
Moisture.....	25.0%	4.0%	0.9%
Ashes.....	13.0%	22.5%	11.8%
Volatiles.....	7.0%	15.0%	16.5%
Calorific value (lower).....	4,570 Cal./kgm.	6,200 Cal./kgm.	6,500 Cal./kgm.
Tar.....	4.3% = 54% theor.	8.28% = 95% theor.	4.2% = 90% theor.
Additional fuel.....	12–15%	6–8%	0%

Figure 14, retains its wooden structure altogether. The sub-bituminous coal of Spain, Figure 15, hardly shows any disintegration. The semi-coke of cannel coal of England, Figure 16, stands carbonization without falling to pieces, and low-grade bituminous coal of Utah, Figure 17, shows a marked sintering effect but no caking, thus retaining its original structure.

The figures indicating numerically the results obtained when working with the Lurgi process are given in Table III.

They are based upon practical work in units of 120-ton throughput per day with German brown-coal or, as in the case of the American lignite—are obtained in an experimental plant. For comparison the figures of the Rolle furnace are added.

You will realize:

1. That in the case of Lurgi plants the increase in throughput above the Rolle furnace is very marked, the Lurgi plants representing large industrial units.

2. That the amount of the throughput itself is dependent upon the structure and physical behavior of the raw material treated, the lignite giving a higher throughput than German brown-coal.

3. That the coke produced is practically dry and—owing to the low temperature carbonization method employed—shows a very high content of volatiles, thus accounting for its high calorific value and its high inflamability.

4. That tar is obtained in the Lurgi process with about theoretical (Al Retort) yield, i.e., nearly twice as much as with the Rolle furnace.

The thermal efficiency of the Lurgi process, based upon the above figures is shown in detail in a Rankin diagram, Figure 18. The very high thermal efficiency of about 85 per cent is reached.

Now about the practical value of the products obtained and their utilization.

About tar I do not want to say here more than a few words, this question being of special importance in Europe, but not so much over here. I may only add that by distillation, a pitch very suitable as a binder for briquetting is to be obtained as well as a quantity of several (some 3) gallons of oil per ton of raw wet lignite. This oil may be very suitable for conservation of timber. It may be that the tar, when properly treated afterwards, will be found useful for road construction, as a binder for gravel.

However, now I should like to dwell upon the importance of the coke obtained, this being the chief product of carbonization.

The coke obtained from the carbonization plant, having retained its structure to a certain extent, is a very valuable fuel for domestic and industrial purposes. In Germany much work has been done to develop an automatic grate for this fuel. The result is the construction of a special nozzle chain grate with artificial draft, showing combustion rate of 175–200 kgm. coke /m^2, this figure not only

reaching, but even surpassing the combustion rate reached with bituminous coal. For the coke produced showing too much disintegration, briquetting will have to be resorted to, making use of the binder produced from the tar distilled. Such briquetted coke will

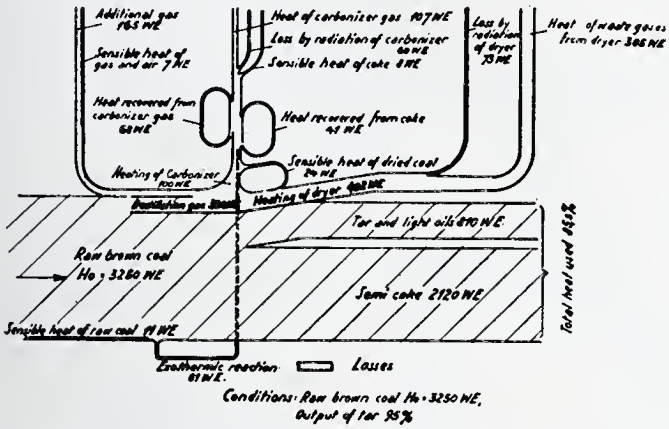

FIG. 18. RANKINE DIAGRAM OF THE "LURGI" PROCESS

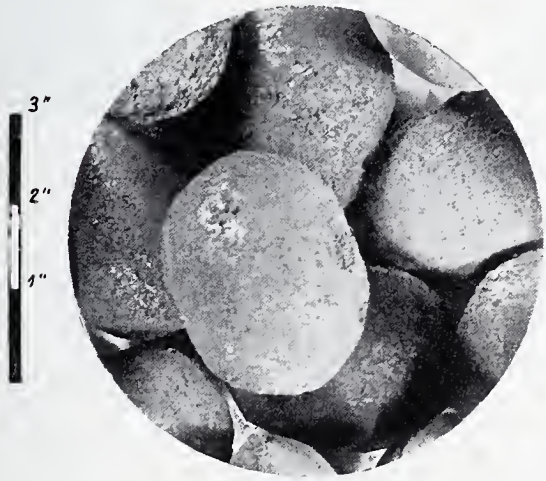

FIG. 19. BRIQUETS OF SEMI-COKE FROM LIGNITE OF NORTH DAKOTA

compete with bituminous coal on account of its good transportability, high calorific value, increased reactivity, and the fact that the ashes of briquets sinter very rarely as experience shows. The North Dakota and Saskatchewan carbonization plant will produce such briquetted coke. An example is shown in Figure 19.

Low temperature carbonization coke of sub-bituminous coal was found to be an ideal material for pulverized coal firing. Extensive tests have confirmed this opinion. Successful experiments were carried out in Germany regarding the use of pulverized semi-coke for railway engines, and for power stations. So much about coke as a fuel.

In conclusion I may add some facts on coke of sub-bituminous coal from a physical-chemical point of view. Owing to its intrinsic structure, forming a system of carbon of high porosity, i.e., high

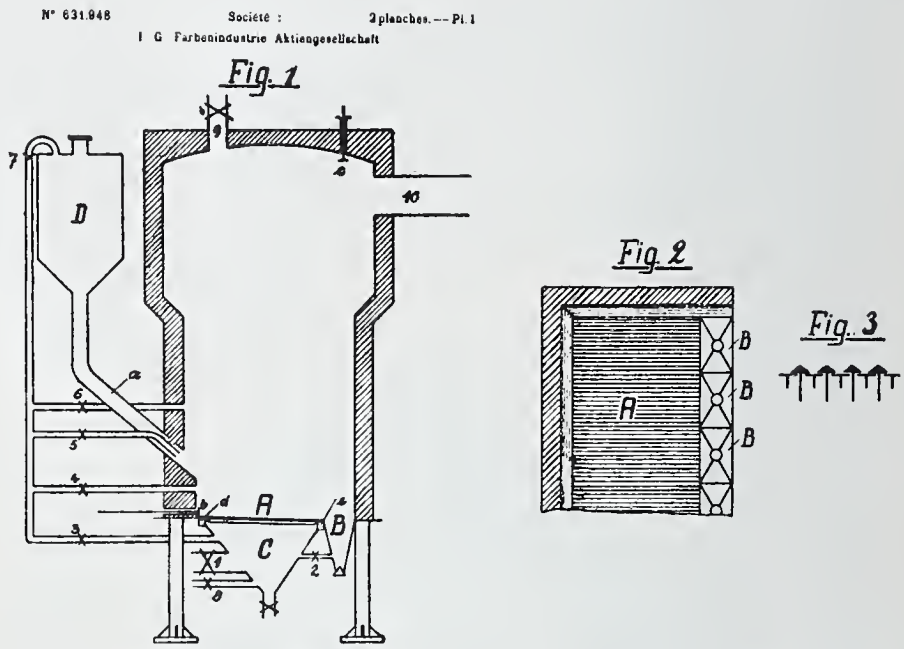

FIG. 20. WATER GAS PRODUCER "WINKLER" SYSTEM

reactivity, such coke must be regarded as a new and valuable raw material for chemical purposes.

A few examples of its utilization:

The production of water gas, being fundamentally important as a source of hydrogen for nitrogen fixation and all hydrogenization purposes, up to now is based entirely on coke of bituminous coal. When using this raw material, the fundamental equation, representing the process is:

$$C + H_2O = CO + H_2 - 31{,}700 \text{ cal.} \qquad (I)$$

the range of working temperature being about 900° to 1000°C. theoretically for 1 Mol. C only 1 Mol. H_2 is obtained.

Efforts have been made to work the process of hydrogen production according to the equation

$$C + 2H_2O = CO_2 + 2H_2 - 21{,}700 \text{ cal.} \qquad \text{(II)}$$

according to which 1 Mol. C yield 2 Mol. H_2.

Until lately no industrial solution for the direct process according to equation II was known. Years ago, the Badische (I. G.) in their Oppau and Leuna works succeeded in developing an indirect catalytic process, turning the CO content of the gas according to equation I catalytically at about 500°C. to CO_2, and H_2, in this way realizing the output of 2 Mol. H_2 for 1 Mol. C.

In German producer gas practice with raw brown-coal, and especially in the carbonization work there, it was however, frequently observed, that hydrogen-production with lignite coke did take place with appreciable velocity already at much lower temperature, at about 500 to 600°C. But at these temperatures the formation of hydrogen is known to follow equation II, according to which 1 Mol. C yields 2 Mol. H_2.

Therefore lignite coal is active enough to react according to the equation II, showing a superiority over coke of bituminous coal with regard to yield and working temperature.

On this basis the question of constructing an efficient hydrogen or water gas producer has found a new and surprising solution. Winkler succeeded in constructing a new producer, which appears to be a sort of Pachuca tank, a cylindrical tank, conical at its lower end, partially filled with lignite coke. Compare Figure 20. If the air or steam current is entered at the conical end, applying such a high current velocity that the whole charge comes into motion—is dug up—the whole mass of the charge is brought into reaction. In this way a throughput of such an apparatus is obtained unknown up to now, amounting up to 1000 tons fuel per day. Thus, as far as I can see, the most ideal water gas- or hydrogen-source is realized in the Winkler producer, charged with carbonized lignite. I think, shortly the bulk of the fixed nitrogen, produced in Germany, will be obtained by such hydrogen of lignite coke.

Another field of application of the highly reactive lignite coke is the production of adsorptive carbon from this material. It has been known for some years, that by partial oxidation of carbonifer-

ous material, like charcoal, adsorptive properties can be attributed to such coke. During the past few years it has been found that brown-coal coke under proper treatment by gaseous oxidation agents can be turned into adsorptive-active-carbon, competing in quality with the best known active carbon, obtained by complicated chemical preparation.

In summing up I would like to say that carbonized sub-bituminous coal, lignite, brown-coal, etc. in Central Europe, has proved to be a very valuable and universal fuel for domestic and industrial use, and that lignite coke has just made its appearance as a new raw material in chemical industry.

Thus it seems to me pretty safe to predict, that on the basis of lignite carbonization a big industrial development is bound to take place in those countries where sub-bituminous coal carbonizaton plants are set to work.

THE LOW-TEMPERATURE CARBONIZATION PLANT AT THE IMPERIAL FUEL RESEARCH INSTITUTE

By Yoshisada Ban

Chemist of the Imperial Fuel Research Institute, Tokio

The industry centering around the low-temperature carbonization of coal has shown remarkable progress within the last ten years. Various systems have been introduced; but as to heating systems, there still remain only two, i.e., the external and internal. Each has certain advantages as well as disadvantages; and when considered from every angle neither can be asserted to be the superior of the other. The selection of the carbonizing system must, accordingly, be decided by taking into consideration the nature of the coal to be used and the character of the main product aimed at.

Plant of the First Stage

At the foundation of the Imperial Fuel Research Institute in 1921, we constructed a low-temperature carbonization plant with an external heating system with the object of testing Japanese coals. The construction and the working results of this plant were fully reported in the Technical Paper No. 1 of the Institute, published in 1925.

The plant consists of 6 vertical retorts made of cast steel, each of which has a height of 10 feet and a section of 2 feet 6 inches by 7 inches at the middle, tapering downward. The retort is heated with horizontal flues of 7 steps, through which the hot gases flow backward and forward up to the uppermost flue and then to the chimney. The heating gases are burned at the entrance of the first, third and fifth flues to maintain the heating temperature uniform throughout the retort. The working is entirely discontinuous, and the coal is charged through the hopper to a retort, where it remains till it reaches a temperature of 500°C., and the semi-coke thus produced, is discharged from the bottom by its own gravity.

The working results of the above described plant, have been successful in dealing with Japanese coal, as long as its caking power is moderate. Though the first stage plant showed good results in operation, yet there remained several points to be improved, i.e.,

1. It requires an extraordinary amount of care to maintain uniform

temperature along the whole surface of the retort. It is a most difficult matter to keep it perfectly uniform.

2. As the working is discontinuous, the retort is always subject to sudden changes of temperature, which cause a considerable fuel consumption.

3. As the temperature of combustion of the fuel gas is moderately high, local overheating, where the combustion takes place, is likely to occur.

4. The semi-coke, discharged in a red hot state, must be quenched with water, and accordingly effects an increase in the fragility which is never desirable.

The defects above mentioned can be remedied if a retort of the proper design is constructed. Under this consideration, we designed a new carbonizing retort for continuous working.

SECOND STAGE PLANT

A new setting was erected in 1924, and the details of the construction were reported by Professor Dr. Oshima, Director of the Institute, at the first International Conference on Bituminous Coal. This new setting also consists of 6 vertical retorts, but cast iron is used in place of cast steel as the retort material. The retort, which is 11 feet high and slightly tapered with a section of 5 inches by 2 feet 6 inches at the center, is wholly covered with carborundum bricks to avoid local overheating as well as to contribute to its durability.

The lower part of each retort is directly connected to a cooling chamber made of cast iron, in which a coke extractor is provided. The coal, charged through a hopper into the retort, descends by its own gravity while it is being carbonized until it reaches the cooling chamber, where the semi-coke thus produced is discharged continuously by an extractor into water, and is then transferred by a belt conveyor to a semi-coke bin. The cooling chamber, around which the air is circulated to cool the semi-coke in it, is water-sealed to save the trouble of opening the door when the coke is discharged; and steam also can be admitted, if necessary, into the cooling chamber.

The new setting, accordingly, seems to be successful as a low-temperature carbonizing plant of external heating, as it can be worked continuously and entirely mechanically. Moreover, except in the case of a single flue, which is to be maintained at the highest temperature desirable, as the charge travels continuously downward through

the retort, no effort is required to keep the whole surface of the retort at a uniform temperature.

The new setting thus perfectly overcomes the defects of the old one and is believed to be one of the most successful so far as the external heating method is concerned. The working results are given in the tables.

The coal employed for the test was of a high volatility and non-caking, the analysis of which is given in Table I.

TABLE I

PROXIMATE ANALYSIS

	NAME OF MINE	MOISTURE	ASH	VOL. MATTER	FIXED CARBON	CAL. V.
1	Takasaka	5.45	18.09	41.63	34.83	5,855
2	Tsuzura	4.34	18.91	43.38	33.37	5,978
3	Okinoyama	10.46	12.47	37.03	40.04	5,735
4	Onedo	4.09	24.63	35.54	35.74	5,596
5	Yubetsu	3.24	20.12	42.13	34.51	6,007
6	Fushun	5.56	13.45	37.67	34.30	6,506
7	Horonai	3.71	9.19	42.77	44.33	6,917

ELEMENTARY ANALYSIS

	NAME OF MINE	MOIS-TURE	ASH	C	H	O	S	N
1	Takasaka	5.89	18.65	58.46	5.06	8.64	2.67	0.63
2	Tsuzura	5.00	19.13	58.56	5.02	7.72	4.01	0.56
3	Okinoyama	10.66	12.01	57.52	4.69	12.93	1.33	0.86
4	Onedo	3.92	24.79	55.31	4.53	10.06	0.45	0.94
5	Yubetsu	3.33	20.37	60.00	5.22	10.01	0.30	0.77
6	Fushun	5.69	13.55	63.55	5.03	10.56	0.61	1.01
7	Horonai	3.92	9.75	69.87	5.52	9.34	0.36	1.24

The assay results of the samples with Fischer's rotary retort are shown in Table II.

The coals were treated by the experimental plant of continuous working type, with and without the admission of steam into the cooling chamber.

Table III shows the carbonizing results when the steam was not admitted, while Table IV gives the results when steam was introduced.

As can be seen from the tables, the results of admitting steam during carbonization are: (1) increase in the yield of tar, (2) increase in the amount of gas, and (3) a decrease in the yield of semi-coke.

TABLE II

	NAME OF MINE	SEMI-COKE	LOW-TEMPERATURE TAR	LIQUOR	GAS AND LOSS
		per cent	*per cent*	*per cent*	*per cent*
1	Takesaka	63.57	15.03	15.86	5.56
2	Tsuzura	64.32	17.19	11.88	6.61
3	Okinoyama	65.23	8.29	19.73	6.75
4	Onedo	72.79	12.93	8.95	5.33
5	Yubetsu	68.94	17.05	8.70	5.31
6	Fushun	66.59	12.17	15.43	5.81
7	Horonai	67.89	15.72	9.73	6.66

TABLE III

CARBONIZING RESULTS WITHOUT STEAM

	NAME OF MINE	MEAN CARBONIZING TEMPERATURE	SEMI-COKE	TAR	GAS BENZENE	GAS	LIQUOR
			per cent	*per cent*	*per cent*	*cbm./ton*	*per cent*
1	Takesaka	523.7	61.50	12.20	0.29	137.2	15.95
3	Okinoyama	530.0	59.77	7.78	0.26	107.8	19.70
4	Onedo	545.2	68.46	11.26	0.21	96.0	12.04
5	Yubetsu	573.9	69.88	11.02	0.30	91.2	9.97
6	Fushun	557.3	66.13	11.68	0.38	111.7	16.50
7	Horonai	575.0	70.28	15.38	0.44	108.5	10.94

TABLE IV

CARBONIZING RESULTS WITH STEAM

	NAME OF MINE	MEAN CARBONIZING TEMPERATURE	SEMI-COKE	TAR	GAS BENZENE	GAS	LIQUOR
			per cent	*per cent*	*per cent*	*cbm./ton*	*per cent*
2	Tsuzura	570.1	63.05	14.68	0.38	148.8	13.88
3	Okinoyama	580.2	58.42	8.99	0.21	201.7	29.06
4	Onedo	574.2	69.52	10.91	0.46	120.0	32.36
5	Yubetsu	568.1	64.05	15.63	0.46	137.8	35.99
6	Fushun	566.9	69.15	11.84	0.38	105.5	22.86
7	Horonai	567.5	68.26	15.90	0.39	126.3	45.48

Comparing the yield of tar in both cases, with and without steam, we have the figures given in Table V, which explain clearly the increase of tar yield when the steam was used during carbonization.

TABLE V

TAR YIELD (PURE COAL BASE)

	NAME OF MINE	ASSAY RESULT	WITHOUT STEAM	WITH STEAM	INCREASE BY USING STEAM
		per cent	*per cent*	*per cent*	*per cent*
2	Tsuzura	22.40	15.96 (Takasaka)	19.13	3.17
3	Okinoyama	11.03	10.32	11.66	1.37
4	Onedo	16.40	14.28	15.31	1.03
5	Yubetsu	22.25	14.14	20.39	6.25
6	Fushun	15.03	13.86	14.62	0.76
7	Horonai	18.05	17.88	18.25	0.37

TABLE VI

COMPARISON OF THE GASES PRODUCED

	NAME OF MINE	STEAM	CO_2	C_mH_n	O_2	CO	H_2	C_nH_{2n+2}	N_2	CAL. VAL. MEASURED
										Cal./cbm.
1	Takasaka	Not used	14.4	3.9	1.3	9.6	24.6	40.1	6.1	6,629
2	Tsuzura	Used	15.9	3.8	0.6	8.9	26.5	39.1	5.2	6,893
3	Okinoyama	Not used	21.3	3.8	0.8	10.2	21.2	28.6	4.1	6,167
		Used	20.3	1.7	0.6	10.9	38.5	25.8	2.2	4,720
4	Onedo	Not used	7.5	3.4	1.4	9.3	22.3	48.3	7.3	7,079
		Used	9.8	6.0	1.0	7.5	19.3	49.5	6.9	7,323
6	Fushun	Not used	8.6	4.4	1.0	9.9	22.8	48.7	4.6	7,555
		Used	8.4	2.7	1.8	9.5	24.4	44.5	8.7	6,664
7	Horonai	Not used	6.1	3.7	1.1	8.9	21.2	48.6	10.4	6,903
		Used	8.2	3.5	0.9	8.3	29.5	44.6	4.0	7,078

By admitting steam during carbonization, the yield of tar can be increased by 1 per cent, which is more than 90 per cent of the yield of tar by the assay retort.

The amount of gas evolved during carbonization also increases when

the steam is introduced. This increase is chiefly due to the decomposition of the steam used, though the temperature is by far lower than in ordinary water gas practice, which can be seen by the analysis of the gas produced.

The gas produced when the steam was admitted during carbonization contains a higher percentage of CO_2 and H_2. Both are the reaction products between steam and carbon at lower temperature,

TABLE VII

COMPARISON OF TAR PRODUCED

	NAME OF MINE	STEAM	SPECIFIC GRAVITY AT 30°C.	DISTILLATE		
				Up to 150°C.	150–200°C.	200–250°C.
				per cent	*per cent*	*per cent*
1	Tsakasaka	Not used	0.9680	5.87	9.82	24.03
2	Tsuzura	Used	0.9775	2.16	7.66	20.02
3	Okinoyama	Not used	0.9668	6.02	11.09	24.26
		Used	0.9869	1.89	4.40	22.31
4	Onedo	Not used	0.9755	2.91	11.64	20.97
		Used	0.9823	2.49	5.49	17.67
5	Yubetsu	Not used	0.9453	1.97	7.12	18.31
		Used	0.9625	2.56	4.82	15.80
6	Fushun	Not used	0.9695	3.72	9.74	22.23
		Used	0.9769	3.27	6.05	20.66
7	Horonai	Not used	0.9659	2.81	5.49	16.90
		Used	0.9781	2.91	6.91	17.00

and consequently the occurrence of water gas reaction during carbonization can be presumed.

The calorific value of the gas produced when steam was used, however, decreases owing to an increase of the content of CO_2 and H_2.

The amount of steam used was usually from 5 to 25 per cent of the coal which was used to examine the effect of the steam during carbonization. From our experience, it can be said that there is no necessity to admit more than 5 per cent of steam against the coal charged, to get a maximum yield of tar.

The character of the low-temperature tar produced is also changed

by steaming. The tar produced by ordinary distillation has a lower viscosity and a larger amount of low-boiling fraction than those obtained when steam is introduced. The difference of the character of the two is undoubtedly due to the decomposition of tar.

One of the principal objects of low-temperature carbonization of coal in these tests was to produce tar oil, capable of being used directly as liquid fuel in place of petroleum. Of the suitability of low-temperature tar as a fuel in Diesel engines very little is known. We tested the tar produced in a single cylinder of a four-cycle vertical type Niigata Diesel Engine, with cylinder dimensions 280 by 416 mm., and a rating of 33 b.h.p. at 230 r.p.m. The engine can be operated both as an air injection engine and as an airless injection unit, but the former was exclusively adopted, so as to keep the conditions constant. The brake horsepower was measured by a Frounde water dynamometer directly connected with the main shaft of the engine.

It was found that the tar oil free from pitch and acid was not at all inferior to the heavy oil from petroleum on the market, while the pitch free oil could not be used satisfactorily under a light load, owing to the occurrence of misfires and detonations. As regards water content, no troubles could be observed throughout the test with oil containing 1.1 per cent of water. The presence of a large amount of tar acid makes the auto ignition temperature higher and the calorific value lower, and is regarded as an undesirable constituent, so far as it is used as a fuel for Diesel engines. Accordingly, the low-temperature tar can provide a Diesel oil of good quality if tar acid only is partially removed.

From an economical standpoint, the time required for carbonization is the most important, as it determines the throughput of the retort. As we have observed that 8 hours' carbonization is sufficient for the former retort, we controlled the speed of the coke extractor to maintain the same rate.

As the effective height of the retort for carbonization is 9 feet, the volume per retort is 2 feet 6 inches by 5 inches by 9 feet = 9.34 cubic feet. If we assume the volume of one ton of coal as 45 cubic feet, the amount of coal which can be charged into a retort is 9.34 ÷ 45 = 208.3 kgm. The amount of coal to be charged into one retort is accordingly 26 kgm. per hour, when the coal is carbonized in 8 hours.

From this calculation, the speed of the coke-extractor was so regulated as to maintain a uniform charge of 26.3 kgm. per hour

throughout the test, and this gave very satisfactory results. The hourly charge of the retort, however, was gradually increased to determine the maximum throughput which the retort could afford with a good result. According to experiment, the retort can be charged to the amount of 30 kgm. per hour without causing any defects and consequently it has been confirmed that 7 hours is enough for the carbonization of coal by the new system.

The working results above described prove the new system of low-temperature carbonization to be a successful one, especially when either the non-caking or a medium-caking coal is used as the charge. However, strong caking coal can not be worked without an elaborate amount of care, and as yet the results have been far from satisfactory.

The Fuel Research Station in England, in 1927, made public a new system of continuous working, the so-called E-type, which was found to be very similar to our system. There remains, however, some differences between the two, which consist chiefly in the following points, viz.:

1. Size of retort. E-type has two retorts of a size of 21 feet high by 6 feet 6 inches by 7 inches, tapering to 6 feet 10 inches by 11 inches, while the setting of ours has 6 retorts of a size of 11 feet high by 2 feet 4 inches by 4 inches tapered to 2 feet 8 inches by 6 inches.

2. Heating flues. The retort is heated by vertical flues in the E-type, while in ours it is heated by horizontal flues.

3. Retort surface. The surface of the retort is exposed to the heating gases in the E-type, but in ours it is covered with carborundum brick to avoid local overheating and to increase its durability.

4. Gas off-takes. The gas off-take ascends from the retort to the hydraulic main in the E-type, while it is placed horizontal to the retort in ours, so as to avoid as far as possible the cracking of tar by dropping down into the retort. The gas outlet in our retort is separated by a plate in the retort from the charging hole so as to protect against the mixing of coal dust.

5. Cooling chamber. The cooling chamber of the E-type cools itself, while in ours, air is circulated around the chamber and the heated air is used for the combustion of the fuel gas.

6. Discharging door. In the E-type, the discharging door of the cooling chamber is sealed by a plate, but in ours the cooling chamber is water sealed.

Though the two settings are similar to each other, yet there are so

many different points, as described above, that the working results of the two cannot, of course, be coincident to each other.

We know little about the results of the E-type, but so far as we understand, there is a remarkable difference between the two as to the time required for carbonization, as a retort of the E-type has a volume of 6 feet 8 inches by 9 inches by 21 feet = 105 cubic feet, it can be charged with 2.22 tons of coal at a time, while the mean throughput of a retort per day is reported to be 3 tons, varying from 2.69 to 4.0 tons. From these data, the mean time required for carbonization in the E-type is calculated to be 18 hours, which is 2.5 times compared to that required in our setting.

We have gained satisfactory results with this sytem of external heating, and we are now going to erect a retort of internal heating, which will be completed by about the end of this year. By the operation of this new system, we believe we can get a better idea as to the selection of the heating system and the effects upon the products caused by the difference of the heating system, so far as Japanese coals are concerned.

THE INFLUENCE OF INORGANIC MATERIALS ON LIGNITE CARBONIZATION

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For almost two centuries man has been distilling coal in one way and another, producing gas, coke and tar products, yet even today the mechanism of the coking process is not understood. It is known that some coals are capable of producing cokes of certain desirable qualities in existing types of equipment, whereas some coals are poorly coking and others non-coking; why the different coals behave as they do upon destructive distillation is not definitely known. In fact so indefinite is our knowledge of the mechanism of the process that we are inclined to speak in such general terms as alpha, beta and gamma compounds, oily and solid bitumens, resinic and ulmic substances and to say that a given coal does or does not coke because it possesses or does not possess one or the other of the above classes of substances depending upon the particular school of thought of which we are adherents. It is generally agreed, however, that a coking coal contains some material which may be termed the binder and the coking process consists of three stages:

1. The binder in the coal fuses, followed immediately by decomposition of any excess binder and formation of a plastic layer. This is accompanied by swelling.

2. Volatile gases are evolved, which develop the cellular structure in the partially formed coke.

3. A secondary contraction takes place followed by decomposition of the evolved hydrocarbons, causing deposition of graphitic carbon on the coke, cementing and hardening it.

Although the mechanism of the complex organic reactions taking place during the carbonizing process is not known, evidence has been presented to show that inorganic substances exert a considerable influence on the course and products of carbonization. Previous to 1914, a number of patents had been recorded covering the addition

of lime or chalk, iron or iron compounds and other inorganic compounds for the purpose of increasing the yield of ammoniacal compounds or producing a more reactive coke. During 1914 Lessing[1] published the results of what appears to be the first scientific investigation of the effect of mineral matter on the primary and secondary products of decomposition. Since that time many other scientists have studied the effect of mineral matter on the coking process and on the general character of the coke. Thus Lessing and Banks[2] reported an increase in char yield accompanied by a corresponding decrease in tar yield when certain inorganic materials were added in small amounts, to sugar, cellulose and coal before carbonizing. In addition they observed in some cases differences in the character and structure of the coke.

Similarly, Professor Cobb[3] and his co-workers observed that certain inorganic materials mixed with coal affected the structure of the coke obtained upon carbonization, and Baehr[4] and Fallboehmer[5] found that the reactivity of a coke could be promoted if iron oxide were added to the coal previous to carbonization.

The influence of mineral matter on the carbonization of the so-called coking coals is now well established. A similar investigation in the case of a non-coking coal has been under way in the University of North Dakota for the past two years.

The lignites of the great plains present an interesting example of a coal that does not coke when carbonized under existing methods. In fact this fuel, extremely hard when freshly mined, slacks very badly on losing its moisture in the air and in the fire produces a bed of fine coals which sifts through the ordinary grate unless a bed of ashes intervenes.

When one realizes that United States Geological Survey estimates indicate that the State of North Dakota alone possesses almost 600

[1] Lessing, J., Gas Lighting (1914), **127**, 570.

[2] Lessing and Banks, J. Chem. Soc (1924), **125**, 2344.

[3] Marson and Cobb, Gas Research Fellowship Report 1925, Gas J. (1925), **171**, 39.

Marson and Cobb, Institution Gas Research Fellowship Report 1926, Gas J. (1926), **175**, 882.

Sutcliffe, Branson, Dent and Cobb, Gas Fellowship Report, 1927, Gas J. (1927), **178**, 895.

[4] Baehr, Stahl and Eisen (1924), **44**, (I) 37.

[5] Baehr and Fallboehmer, Gas u. Wasserfach (1926), **69**, 909–12; 929–32; 943–6.

billion tons of this fuel and that lignite and sub-bituminous (in other words low rank) coals constitute over one-half of the existing reserve in the United States it will be appreciated that any studies leading to improvements in these fuels or their use are of fundamental and increasing importance to this country.

The average proximate and ultimate composition of the lignites of North Dakota are given in Table I.

TABLE I

As Mined	*per cent*	*Dry-ash free*	*per cent*
Moisture	36.0	Carbon	68.0
Volatile matter	27.0	Hydrogen	5.5
Fixed carbon	30.0	Oxygen	24.5
Ash	7.0	Nitrogen	1.0
Thermal value in B.t.u. per pound	6000–7000	Sulfur	1.0

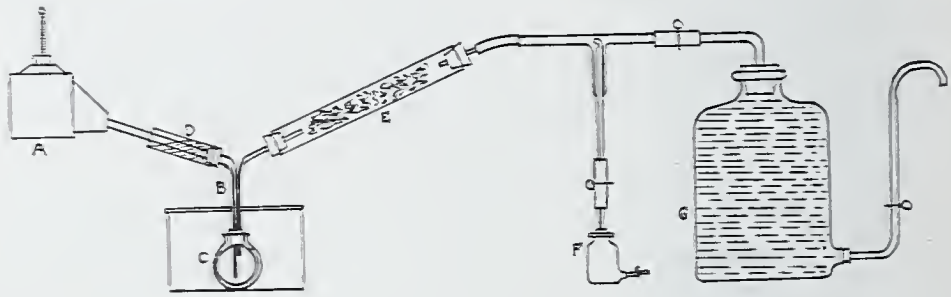

FIG. 1. DIAGRAM OF CARBONIZATION APPARATUS

A, retort; *B*, adapter; *C*, tar receiver; *D*, cooler; *E*, glass wool filter; *F*, gas sampler; *G*, gas receiver.

Previous studies at the University of North Dakota[6] have indicated that these lignites are low in tar as well as high in moisture and cannot be briquetted successfully in the raw state. If, however, the coal is carbonized under conditions representing roughly a mean between high and low temperature processes a hard reasonably unabsorptive char or semi-coke is obtained. When briquetted with small amounts of coal tar pitch, flour and bituminous slack for binder,

[6] Babcock and Odell, "Production and Briquetting of Carbonized Lignite," Bulletin 221, U. S. Bureau of Mines, Washington, D. C. (1923).

this char produces a good domestic fuel that withstands shipment and weathering, ignites easily and does not slack in the fire.

This paper presents the results of experiments made to determine the influence of inorganic materials on the carbonizing process and products.

EXPERIMENTAL

Materials

The lignite used in all the experiments was taken from the Truax-Traer mine at Velva, North Dakota. The lump coal was air dried and then ground so that all passed through a 20 mesh sieve. In order that the effect of any added reagent might not be masked by the mineral matter in the coal, the ground material for the early experiments was washed by passing with 2:1 hydrochloric acid and, in some cases, treated with hydrofluoric acid.

The reagents used were of the variety usually designated as c. p. although such purity was not considered absolutely necessary.

Apparatus

The complete carbonizing apparatus used in the first five series of experiments is illustrated in Figure 1. The retort (*A*) was of aluminum, designed and used by Dr. Franz Fischer[7] in his researches on German coals, excepting in Series IV when a similar retort constructed of copper was substituted owing to the high temperature required. An adapter (*B*) was sealed to the offtake of the retort and provided with a water jacket (*D*) to prevent softening of the cement during a run. A 500 cc. round bottom flask (*C*) immersed in an ice bath was the condensing receiver. The outlet tube from this flask led to a glass wool filter to trap any non-condensed oils. A continuous mercury sampling device (*F*) removed a portion of the gases for analysis. A large calibrated aspirator bottle (*G*) served as a gas holder. Procedure:

The composition of the mixtures carbonized is given in Table III. All of the mixtures represent an amount of reagent equivalent to 5 per cent of the compound assumed to be formed. In all experiments from 150 to 225 grams of mixture were carbonized and the

[7] "The Conversion of Coal in Oils," Fischer and Lessing, D. Van Nostrand Company, New York, 1925, page 25.

compound formed excepting in the case of sodium carbonate was assumed to be the higher oxide.

The proper amount of reagent to be added was dissolved in water and the solution ground together with the lignite in a mortar. Briquets were made from this mixture either in a small cupel machine or in a Riehle compression machine. The briquets were then weighed, placed in the retort and the lid tapped on, all three opera-

TABLE II

MOISTURE AND ASH CONTENT OF LIGNITE

	MOISTURE	ASH	REMARKS
	per cent	*per cent*	
Series I	10.25	0.82	Washed coal
Series II		1.00	Washed coal
Series III	11.24	5.02	Unwashed coal
Series IV	7.83	0.94	Washed coal
Series V	13.71	7.55	Unwashed coal

TABLE III

COMPOSITION OF MIXTURES

1.	95 g. lignite, 25 ml. H_2O
2.	95 g. lignite, 16.8 g. $FeCl_3 \cdot 6H_2O$, 20 ml. H_2O
3.	95 g. lignite, 5 g. Na_2CO_3, 30 ml. H_2O
4.	95 g. lignite, 5 g. SiO_2, 25 ml. H_2O
5.	95 g. lignite, 23.66 g. $AlCl_3 \cdot 6H_2O$, 20 ml. H_2O
6.	95 g. lignite, 6.22 g. Cu_2Cl_2, 25 ml. H_2O
7.	95 g. lignite, 5 g. S, 25 ml. H_2O
8.	150 g. lignite, 65 ml. H_2O
9.	150 g. lignite, 35 g. $AlCl_3 \cdot 6H_2O$, 65 ml. H_2O
10.	150 g. lignite, 51.6 g. $Al_2(SO_4)_3 \cdot 18H_2O$, 20 ml. H_2O
11.	150 g. lignite, 39.6 g. $MgCl_2 \cdot 6H_2O$, 10 ml. H_2O
12.	150 g. lignite, 26.6 g. $FeCl_2 \cdot 6H_2O$, 20 ml. H_2O
13.	150 g. lignite, 7.89 g. SiO_2, 60 ml. H_2O

tions of mixing, briquetting and weighing being carried out as rapidly as consistent with good workmanship in order to prevent any great loss of water by evaporation.

After the weights of flask and glass wool filter were obtained the rest of the train was connected and the retort heated to 500°C. in 15 minutes, at as uniform a rate as possible. The temperature was held between 500° and 510° for a period of $1\frac{1}{2}$ hours. On discon-

tinuing the heating and removing the adapter and flask, the retort was stoppered to prevent absorption of moisture by the char during cooling. The weights of the flask and distillate, the glass wool filter, the adapter and tar, the volume of the gas and its temperature, were

TABLE IV

PER 100 GRAMS ORIGINAL LIGNITE

REAGENT	MIXTURE NUMBER	GRAMS CHAR LESS ASH			
		Series I	Series II	Series III	Series IV
Blank	1	61.4	60.4	56.7	48.3
$FeCl_3 \cdot 6H_2O$	2	63.5	62.7	60.3	51.9
Na_2CO_3	3	58.4	58.1	55.6	48.5
SiO_2	4	60.9	60.5		
$AlCl_3 \cdot 6H_2O$	5		59.7	59.8	50.3
Cu_2Cl_2	6		59.4	55.1	51.1
S	7	62.8			

Maximum temperature Series I, II, III, 510°C.; Series IV, 850°C.

TABLE V

PER 100 GRAMS ORIGINAL LIGNITE

REAGENT	MIXTURE NUMBER	GRAMS CHAR LESS COMPOUND FORMED				GRAMS FIXED CARBON		
		Series I	Series II	Series III	Series IV	Series I	Series III	Series IV
Blank	1	62.3	61.4	61.8	49.2	49.0	45.2	47.6
$FeCl_3 \cdot 6H_2O$	2	64.7	63.5	65.3	52.9	51.1	50.2	51.1
Na_2CO_3	3	58.7	58.2	60.1	47.0	47.9	43.8	46.3
SiO_2	4	61.8	61.5			47.8		
$AlCl_3 \cdot 6H_2O$	5		61.4	64.9	52.0		50.6	49.6
Cu_2Cl_2	6		59.8	59.8	51.9		46.1	50.4
S	7					50.1		

all recorded; when the retort was cool, the weight of the char was obtained. Series IV was run at a maximum temperature of 850°C.

The tar and water of the distillate were fractionated by a modified xylene distillation method. A known weight of xylene was added to the tar and water distillate of the carbonization, and the mixture distilled in the usual manner. The xylene and water distil over at approximately 100°C., and separate into two phases on condensing.

The weight of the tar residue and of the water can then be determined.

The gases were analyzed by means of a standard modified Orsat apparatus of the Bureau of Mines type.

Proximate analyses were made of briquets and chars in most of the tests. As a check, ultimate analyses were made of the chars and tars of one series of runs.

In each series check determinations were made and blanks run at beginning during middle and at end of the series. The moisture and ash composition of the lignites used and the relative composition of the briquetted mixtures are given in Tables II and III.

Results

The averaged results of the experiments showing the effect of a few inorganic materials on the yields of char, tar, fixed carbon and gas, as well as the relative distribution of carbon between char, tar and gas are given in Tables IV to X.

DISCUSSION

Effect on Yields of Char, Tar and Gas

The proper method of comparing char yields is difficult to determine. It is certain that the inorganic substances can and in most cases probably do exist in entirely different forms in the char than in the ash of the char. The form of the mineral constituent of the char is not known. Lessing and Banks[8] made their calculations on the basis of ferric oxide and aluminum oxide in the cases of iron and aluminum chlorides. Lidov[9] claims a coke having metallic iron distributed throughout. The system however is an exceedingly complicated one and even if the equilibrium composition were calculated there is no assurance that equilibrium has been reached under the conditions of the experiment. Baehr[10] assumes the presence of iron silicides and carbides in coke. Powell[11] found that pyrites gave ferrous sulfide and an iron-carbon compound during carbonization.

[8] Loc cit., page 2346.
[9] Lidov, Met. Chem. Eng., **10**, 593.
[10] Loc cit., page 606.
[11] Powell, Ind. Eng. Chem. (1921), **13**, 33.

Others have suggested the formation of silicates. Heterogenous mixtures of these compounds may be present. Even less is known of the nature of the aluminum and copper compounds in cokes. In our observation, metallic copper was certainly deposited in some cases, and not in others. Silica and sodium carbonate probably remain unchanged, though Marson and Cobb[12] assume sodium carbonate changes to sodium oxide, even for cokes prepared at 500°. Obviously the oxygen content of the coal, the inherent mineral matter, the temperature of carbonization, time and rate of heating, and other factors will have an effect on the mineral matter of the chars. However, most of the compounds likely to be formed are of lower molecular weight than those used in the calculations, and

TABLE VI

REAGENT	MIXTURE NUMBER	GRAMS TAR PER 100 GRAMS ORIGINAL LIGNITE				LITERS OF GAS PER 100 GRAMS ORIGINAL LIGNITE		
		Series I	Series II	Series III	Series IV	Series I	Series II	Series III
Blank	1	5.01	3.90	2.07	2.09	8.2	8.9	11.7
$FeCl_3 \cdot 6H_2O$	2	1.85	1.75	1.25	2.61	9.4	10.2	11.5
Na_2CO_3	3	3.51	2.77	1.59	1.39	10.9	11.5	13.4
SiO_2	4	4.60	3.64			8.9	9.3	
$AlCl_3 \cdot 6H_2O$	5		2.91	1.77	1.91		10.6	10.6
Cu_2Cl_2	6		2.58	1.64	1.72		12.0	12.1
S	7	2.63				11.5		

the deviations caused by the catalyst therefore will appear greater, in most cases, than those shown. For example, if the $FeCl_3$ were assumed to deposit metallic iron only, the amount of "char less compound formed" would be increased from 63.5 to 65.0 grams, in No. 2, Series II; the deviation from the blank is increased. Calculating the cuprous chloride to the pure copper basis, rather than to the cupric oxide basis, the amount of "char less compound formed" in No. 6, Series II, would be increased from 59.8 to 60.8 grams, thus decreasing the deviation from the blank. However, the general trend of the effect of the mineral matter will not be changed greatly by calculating to the alternative basis.

The deviations between duplicate runs show a maximum of 1.9

[12] Loc. cit., page 39.

per cent, calculated from the average of the duplicates, consequently the deviations noted between blank and treated chars are considered to be real, outside the limit of variance of the duplicates, which at the most is not more than 2 per cent.

Evidently the ferric chloride hydrate causes a positive deviation from the blank equivalent to an increase of some 3 to 4 per cent in the quantity of char from the washed coals, and 5 to 6 per cent for the unextracted coal. A similar increase in char yields is caused by magnesium chloride hydrate in Series V. The sodium carbonate, on the other hand, lowers the char yield between 5 and 6 per cent for the washed lignites and between 2 and 3 per cent for the unwashed. The aluminum chloride hydrate seemingly causes an in-

TABLE VII

SERIES V

Yield per 100 grams dry lignite

REAGENT	MIXTURE NUMBER	GRAMS CHAR LESS ASH	GRAMS CHAR LESS COMPOUND FORMED	GRAMS FIXED CARBON	GRAMS ULTIMATE CARBON
Blank	8	59.3	67.7	48.0	48.9
$AlCl_3 \cdot 6H_2O$	9	59.1	66.8	50.9	49.8
$Al_2(SO_4)_3 \cdot 18H_2O$	10	63.8	74.9	49.2	50.6
$MgCl_2 \cdot 6H_2O$	11	60.8	69.3	53.6	52.0
$FeCl_3 \cdot 6H_2O$	12	61.9	70.0	52.7	51.5
SiO_2	13	59.0	68.1	47.2	50.1

crease in Series III, but not in Series II, whereas aluminum sulfate hydrate causes a large increase in the char yield. Cuprous chloride produces doubtful lowering in Series II, but considerable lowering in Series III. Silica is without effect in any case, and nothing can be concluded concerning the effect of sulfur.

The inherent ash of the lignite seems to mask the effect of the catalyst in some cases and augment it in others. These may be only apparent effects caused by the formation of heavy complex compounds between inherent and added matter, or they may be real increases due to additive effects of iron or aluminum in the ash.

In every case, the amount of tar is lowered by the added substance. The lowering is greatest in the case of the iron chloride, which checks up with the increase of char recorded for this reagent. When the

tar yields for the blanks of the extracted and unextracted coals are compared, a considerable lowering is noticeable. This undoubtedly is due to the mineral matter of the unwashed coal, whatever it may be. In those cases where the amount of char and tar are both lowered, increases in carbon may be looked for in the gases. The deviations of the tar yields between duplicates are quite large, the maximum being some 9 per cent calculated from the average of the duplicates, though in most cases it is less than 4 per cent. The

TABLE VIII

PERCENTAGE DEVIATION FROM BLANK

REAGENT	GRAMS CHAR LESS ASH				
	Series I	Series II	Series III	Series IV	Series V
$FeCl_3 \cdot 6H_2O$	+3.4	+3.8	+6.3	+7.5	+4.4
Na_2CO_3	−4.9	−3.8	−1.9	+0.4	
SiO_2	−0.8	+0.2			−0.5
$AlCl_3 \cdot 6H_2O$		−1.2	+5.5	+4.1	−0.3
Cu_2Cl_2		−1.7	−2.8	+5.8	
S	+2.3				
$Al_2(SO_4)_3 \cdot 18H_2O$					+7.6
$MgCl_2 \cdot 6H_2O$					+2.5
	GRAMS CHAR LESS COMPOUND FORMED				
$FeCl_3 \cdot 6H_2O$	+3.9	+3.4	+5.7	+7.5	+3.4
Na_2CO_3	−5.8	−5.2	−1.1	−4.5	
SiO_2	−0.8	+0.2			+0.6
$AlCl_3 \cdot 6H_2O$		0.0	+5.0	+5.7	−1.3
Cu_2Cl_2		−2.6	−3.2	+5.5	
$Al_2(SO_4)_3 \cdot 18H_2O$					+10.6
$MgCl_2 \cdot 6H_2O$					+2.4

deviations caused by the catalyst are much greater, amounting to as much as a decrease of 63 per cent in the case of the ferric chloride, in Series I. The xylene distillation method of fractionating the water and tar is not refined enough to give accurate results. Difficulty is encountered in distilling to absolute dryness without cracking the tars into lighter oils which may then pass over. It is more than likely, too, that some of the added mineral matter sublimates during carbonization, and passes into the condensing receiver. This will cause greater apparent tar yields. Such a case is particularly

noticeable in the iron chloride tar of the high temperature series, where it was easy to detect the iron chloride in the tar.

The gas yields are not considered accurate to more than 500 cc. and show but little variation from the blank runs, except in the case of the sodium carbonate and cuprous chloride, where considerable increases were obtained.

The general trend of the effect of mineral matter on char yields was the same for the high temperature runs of Series IV as for the low temperature tests. The tar yields are not exact. The character of the chars was of chief interest, and it was not expected that checks on char and tar yields would be obtained under the difficulties involved in the maintenance of uniform conditions during carbonization.

Effect on Distribution of Carbon

The distribution of the carbon, as shown by Table X, Series II, is interesting and worthy of discussion. Due to difficulties in gas analyses and to the inexact volumes of gases, the amount of carbon in the gas is not very accurate. Likewise the carbon and hydrogen analyses of the tars were difficult to check. For instance, the aluminum chloride tar, when heated, caused explosions forceful enough to break the combustion tube. It is noticeable that checks in the composition of tars from duplicate runs were not obtainable. This may be due largely to the xylene distillation method. The carbon of the char constitutes the greater part of the total, and as this determination is quite accurate, the carbon totals check out fairly well.

Though no reliance can be placed on the figures as being quantitatively exact, the trend of the position of the carbon can be observed. Compared to the blank, iron chloride causes less carbon in the tar, and about the same amount in the gas. Sodium carbonate slightly lowers the carbon in the tar, and drives more into the gas. This checks qualitatively with the results of Taylor and Neville[13] who showed that the presence of sodium carbonate increased the interaction of carbon and carbon dioxide as well as carbon and steam at 570°C. sufficiently to yield about eight times as much gas as was obtained with no catalyst. Those substances causing little or no change of carbon in the char, seem to lower the amount in the

[13] Taylor and Neville, J. Am. Chem. Soc. (1921), **43**, 2055.

tar and increase the amount in the gases. These increases and decreases cannot be expected to be large, and therefore more accurate methods are necessary before quantitative conclusions may be drawn.

Effect on Character of Chars

The chars from the blank runs were soft fine powders showing no coking structure or tendency towards coherence of the particles. The charred briquets usually were crumbled and broken when the retort was opened. The chars from the sulfur, sodium carbonate, silica and cuprous chloride briquets were similar to the blanks,

FIG. 2. COMPARISON OF PSEUDO-COKES ($AlCl_3 \cdot 6H_2O$ MIXTURE) WITH ORDINARY CHAR

namely, soft and non-coherent. The chars from the briquets containing ferric chloride seemed to be somewhat harder. The charred briquets usually retained their shapes on opening the retort although they were badly cracked; when handled they broke and crumbled easily but into particles somewhat larger than in the case of the untreated coal.

The greatest difference was observed when the briquets containing the hydrated chlorides and sulfates of aluminum were carbonized. The charred briquets were firm and hard and came from the retort without breaking. In fact they could be dropped to the floor from a height of one to two feet without breaking. In some cases they possessed a bright silvery metallic luster resembling metallurgical coke. In other cases the luster was black resembling petroleum

coke. The hardness of these lustrous carbonized briquets was three, equalling the hardness of a sample of petroleum coke, and but a little lower than that of a sample of metallurgical coke. When tapped the charred briquets emitted a metallic ringing sound. Figure 2 is an illustration of two chars made with $AlCl_3 \cdot 6H_2O$ compared to a pile of char from one of the blanks.

TABLE IX

PERCENTAGE DEVIATION FROM BLANK

REAGENT	GRAMS FIXED CARBON IN CHAR				GRAMS TAR		
	Series I	Series III	Series IV	Series V	Series I	Series II	Series III
$FeCl_3 \cdot 6H_2O$	+4.3	+11.1	+7.4	+9.8	−63.1	−74.1	−39.6
Na_2CO_3	−2.2	−3.1	−2.7		−30.0	−29.0	−23.2
SiO_2	−2.2			−1.7	−8.2	−6.7	
$AlCl_3 \cdot 6H_2O$		+11.9	+4.2	+6.0		−25.4	−14.5
Cu_2Cl_2		+2.0	+5.9			−45.5	−20.8
S	+2.2				−47.5		
$Al_2(SO_4)_3 \cdot 18H_2O$				+2.5			
$MgCl_2 \cdot 6H_2O$				+11.7			

TABLE X

SERIES 2

REAGENT	MIXTURE NUMBER	DISTRIBUTION OF CARBON GRAMS CARBON PER 100 GRAMS LIGNITE			
		Char	Tar	Gas	Total
Blank	1	50.1	3.1	4.3	57.5
$FeCl_3 \cdot 6H_2O$	2	53.3	1.3	4.0	58.6
Na_2CO_3	3	49.0	2.2	5.6	56.8
SiO_2	4	51.0	2.9	4.4	58.3
$AlCl_3 \cdot 6H_2O$	5	51.8	2.2	4.8	58.8
Cu_2Cl_2	6	52.5	2.0	4.4	58.9

Under the microscope a finely cellular structure is visible and it appears as though intumescence had occurred during the carbonization process. Figures 3 and 4 are photographs of specimens magnified ten diameters. This was so unusual for lignites of North Dakota that a special study of the formation and structure of these pseudo-cokes was begun. A number of other inorganic reagents were tried out, the test being made by carbonizing the briquets in covered

TABLE XI

EFFECT OF REAGENTS ON CHARACTER OF CHAR

REAGENT	CHARACTER OF CHAR
$AlCl_3 \cdot 6H_2O$ (lignite 200 mesh)	Hard—form preserved
$AlCl_3 \cdot 6H_2O$ (lignite + Ill. Coal)	Hard—coke-like
$Al_2(SO_4)_3K_2SO_4 \cdot 24H_2O$	Hard—coke-like
$Al_2(SO_4)_3 \cdot 18H_2O$	Hard—lustrous silvery char—form preserved
$MgCl_2 \cdot 6H_2O$	Form preserved—fairly hard
$MgSO_4 \cdot 7H_2O$	Form preserved—soft
$Al(NO_3)_3 \cdot 9H_2O$	Form preserved—hard outside, soft inside
$Cr(NO_3)_3 \cdot 9H_2O$	Hard shell—soft inside
$SrCl_2 \cdot 6H_2O$	Hard shell—soft inside
None (Blank)	Char soft and crumbly
$AlCl_3$ (anhydrous + dry lignite)	No caking—very soft, evidence of retort carbon
$Al_2(SO_4)_3$ (anhydrous + dry lignite)	Soft crumbling char
CaO	Soft char
$NaCl$	Soft char
KCl	Soft char
K_2CO_3	Soft char
$Na_2CO_3 \cdot 10H_2O$	Soft char
Al_2O_3	Soft char, unlike hydrated chloride and sulfate
$CaSO_4 \cdot 2H_2O$	Very soft char
$CaCO_3$	Very soft char
Mg_2CO_3	Soft char
$KHSO_4$	Very soft char
FeS_2	Soft char
FeS	Soft char
SiO_2	Soft char
$Ca(OH)_2$	Soft char
$FeCO_3$	Soft char
$Ni(NO_3)_2 \cdot 6H_2O$	Soft char
$FeCl_3 \cdot 6H_2O$	Very slight caking—crumbled into larger lumps than without reagent
$FeSO_4 \cdot 7H_2O$	Soft char
H_2SO_4	Soft char
$BaCl_2 \cdot 6H_2O$	Soft char
$Ca(OCl)_2$	Soft char
$CaCl_2 \cdot 6H_2O$	Soft char
PCl_5	Very soft char
$Fe(NO_3)_3 \cdot 9H_2O$	Soft char
$Cu(NO_3)_2 \cdot 3H_2O$	Soft char

crucibles placed in an electric furnace maintained at 525°C. The results of these tests are included in Table XI.

The fact that the anhydrous chloride and sulfate of aluminum were without any coking action on the lignite suggested that the phenomenon might be due to the hydrolysis of the salts during the

FIG. 3. PHOTOMICROGRAPH OF PSEUDO-COKE (10 DIAMETERS) FROM $Al_2(SO_4)_3 \cdot 18H_2O$ MIXTURE

course of the reaction. The hardening effect could then be ascribed to the presence of HCl or SO_3 during the carbonizing process. This is evidently not the case for lignite carbonized in the presence of HCl and SO_3 gases produces a crumbly char entirely unlike that obtained when the hydrate of aluminum chloride and sulfate are present. In the case of the anhydrous aluminum chloride experiment an exceedingly fine black form of carbon resembling lamp

black was evidence of catalytic cracking of some of the carbon compounds originally present in the lignite.

The mechanism of the formation of the coke-like char which we have designated a "pseudo-coke" appears to be as follows: The hydrated salt melts, dissolving in its own water of crystallization

FIG. 4. PHOTOMICROGRAPH OF PSEUDO-COKE (10 DIAMETERS) FROM $Al_2(SO_4)_3 \cdot 18H_2O$ MIXTURE

(Note grains of charred lignite showing no fusion embedded in structure)

and this solution is capable of wetting the particles of lignite. As the water is driven off the mixture forms a pasty mass through which the evolved gases must pass as the carbonization proceeds. In the presence of the inorganic material secondary decomposition or cracking of the hydrocarbons takes place forming the hard graphitic layer. The pseudo-coke is finally made up of a cellular structure of

carbon and inorganic substance (possibly an oxide of aluminum). This is evident from an experiment whereby the pseudo-coke was digested in hydrochloric acid for some time. The lumps could then be crushed easily in the hand and the solution contained aluminum. The grayish flakes which the authors consider to be graphite from x-ray crystallographic evidence could still be detected under the microscope in the residue from the acid treatment. The above mechanism is further indicated by some experiments in which various cokes, chars and charcoal were briquetted with hydrate of aluminum chloride and sulfate and then carbonized at 525 degrees. In each case the form of the briquette was preserved in the char. However the chars were soft and crumbled under pressure of the finger and lacked the luster of the lignite pseudo-cokes. This indicates that the inorganic hydrate is responsible for the caking and the catalytic decomposition of the volatile carbon compounds causes the hardening and graphitic luster.

SUMMARY

1. Inorganic materials may exert a specific effect on the structure of the char as well as the yield of char, tar and gas from the carbonization of Velva lignite. It seems essential that one be cautious in predicting the effect of ash material from results of experiments of this nature without being certain that the added material is chemically identical with the inherent mineral matter in the coal in question.

2. Hydrates of aluminum chloride, sulfate and nitrate, magnesium sulfate and chloride and strontium chloride alter the structure of the char produced yielding a hard pseudo-coke differing materially from the soft powdered char of the untreated coal, whereas the anhydrous salts produce soft, fine chars.

3. Ferric chloride hydrate increases the yield of char at the expense of the tar.

4. Sodium carbonate decreases char and tar yields and increases gas yields.

5. Silica is without effect.

6. A mechanism for the formation of pseudo-coke is suggested.

NOTES ON THE USE OF SMOKELESS PULP BINDERS FOR BRIQUETTING

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The trend of development, properties and uses of binders other than pitch, and the early development work on "pulp" binders have been discussed by the authors in a paper contributed to the South Wales Institute of Engineers and published together with the discussion on the paper in their Proceedings in 1926. It seems probable that the art of briquetting will become in future a more important method for "beneficiation" of fuels than seemed likely in view of its disappointing past history.

It is not generally realized that in considering the economics of briquetting it is insufficient to base estimates upon the mere market value of the bituminous coal, anthracite, or semi-coke fines. Where there has been expenditure on screening, washing, or separation by any other means, the cost must be fairly allocated, and above all, the fines must be debited with their fair proportion of the cost of mining and raising the coal. This means that where no market is profitably available for carbonization or steam raising, there is inevitably a loss on the sale of fines which in an extreme case may be as high as double the value of the lump coal sold. Modern briquetting methods may thus be used to minimize an otherwise serious loss or even to convert the loss into a profit. It follows that even propositions which on preliminary examination appear wholly unsuited for briquetting operations may be worth detailed investigation, particularly when it is feasible to use a binder which does not materially affect the properties of the fines nor increase their smoke or nuisance production. In an extreme case such briquetted fuel could be sold alongside of or mixed with the original lump fuel.

Undoubtedly the binder which approximates most closely to the character of coal itself is peat, since the humic fermentation through

which peat has passed was experienced also by the vegetation prior to its conversion into coal. Although the use of peat in briquetting has figured in patent literature for many years, it has never become widely used on an important industrial scale. The reason for this probably lies in the fact that the distribution of peat is somewhat localized, and its constitution is subject to very wide variations, only certain deposits or parts of a deposit having sufficient humus content to make it possible to use it as a binder. Moreover, compared to recently rotted vegetation, peat is low in the mucilaginous products of decomposition, these having been leached out by prolonged action of water.

Although recently rotted vegetation would produce better results than peat, the possibility of obtaining it in quantities sufficient for use in large scale briquetting is very remote, while the intentional collection of fresh material would not be feasible owing to the prolonged period required for fermentation and the low yield of humus obtained. In recent years, however, the humic fermentation of cellulose has received particular study and an established method now exists of obtaining high yields of humus and mucous from soft vegetable waste in much shorter time by stimulating the humus forming soil bacteria always present on plant tissue. The method consists of treating the damp waste with a bacterial food in powder form and at the conclusion of 2 to 5 months according to the nature of the material a rotted product amounting to 85 per cent of the original weight is obtained with substantial humus and mucous content. This product has merely to be rendered alkaline to convert the humus into the disperse state to be ready for use as a highly efficient smokeless binder.

The coal strike in England and the unsatisfactory international fuel situation in all parts of the world naturally delayed the commercial development of "pulp" binder which is the name applied to the alkaline product by the Pulp Binders Development Company, Ltd., of Kimberley, South Africa, who own the patents and for whom the authors are consultants.

Although some hundreds of tons of pulp binder ovoids were manufactured in 1926 in a full scale plant, actual commercial manufacture will only commence in Spain and elsewhere during 1929 using straw and other vegetation as the raw material. The preparation of a pulp binder may be briefly described as follows:

The raw material, consisting of grass, straw, bagasse or other non-lignitic vegetable tissue, is laid on hard ground in stacks having an

area of preferably about 15 by 10 feet. Each layer of about 6 inches in thickness is first wetted and then sprinkled with the dry chemical preparations which consists incidentally of well-known heavy chemicals obtainable at stable prices in all parts of the world. A second layer is then laid down and wetted and sprinkled with the preparation. This method of stacking is continued until the entire heap is about 12 feet high.

Different materials require different quantities of reagents, but usually 5 per cent reckoned on the dry weight of the material is sufficient excepting for materials like straw, when 7½ per cent should be used. Loose-lying materials, such as straw, are preferably crushed or bruised prior to making into a stack which otherwise becomes too loose packed. On the other hand, if the material naturally lies rather closely such as freshly cut grass, no such treatment is required as it is essential that access of air into the interior of the heap is not completely excluded.

When stacked in this way, the material shows a heat reaction within 24 hours and sinks somewhat rapidly. The duration of fermentation is variable, depending upon the external temperature and partly with the nature of the original material. Usually 2 to 4 months are required (grass, comfrey and beet waste require only a few weeks) and during this time the heap should be kept wet but not sodden with water and should be turned sides into middle about once in three weeks. The mass when sufficiently fermented should be dark brown or almost black in color and when rubbed in the hands should become a practically structureless plastic mass. The material is then taken from the stack and placed in an edge runner mill or masticator, and milled up with 1 to 6 per cent of its weight of soda calculated on its dry weight. After 5 to 10 minutes milling, the binder is ready for use, and in continuous working is passed by a regulated feed into a double differential mixer, where it is roughly but evenly distributed through the coal. The mixture then passes to a larger edge runner mill, where it is milled for such a time as is necessary to develop the maximum cohesiveness of the coal and binder mixture. Some experience will be required in determining the relative amounts of binder and moisture necessary, and in fixing the duration of milling, the criterion being the development of plasticity of the mixture shown by its capability of being balled up by the pressure of the hands yet leaving the hands substantially clean and dry. Further additions of water may or may not be required. These details are important, and

vary with the nature of the fuel, its grading, and several other factors, and not until the requisite cohesiveness has been obtained is the mixture ready to be pressed.

The pressing of the mixture of coal and binder can be done either hot or cold and can be carried out in any of the standard forms of briquette presses such as an ovoid press, without modification. Pressure is only needed for increasing the density of the briquettes, which on leaving the press are tough, but somewhat soft. The briquettes or ovoids are passed through a drier of the conveyor type in which no special or complicated conditions need be observed, care however being taken that the temperature of the briquettes themselves does not rise above 150°C. When dry the ovoids are substantially weatherproof and if sold along with lump coal, would probably require no further waterproofing treatment. For sale as a manufactured fuel, where storage under normal conditions may be necessary, a superficial waterproofing treatment such as a short immersion in a dilute solution of crude soap followed by a similar immersion in dilute aluminum sulphate solution is sufficient waterproofing owing to the insolubility of the binder itself. This treatment can be carried out at a reasonable cost, having regard to the value of crude soap.

It should be noted that "pulp" binder itself when dried under the above conditions is not only insoluble in water, but is not easily wetted, and generally has the consistency of hard tough leather. Its ash content is low, the calorific value about half that of coal, and when used in the proportion of about 5 per cent dry weight on the weight of the fines to be agglomerated, the presence of say 0.1 per cent of soda in the coal rarely has any material influence upon the fusibility of the ash or clinker. For anthracite, semi-coke, mature lignites of high volatile content, and for fuel developments in countries overseas where pitch and other binders are commercially and technically impracticable, pulp binders present outstanding advantages and are likely to be increasingly used. In this connection due regard must be had to the value of smokelessness, to the free burning properties conferred by them on the agglomerated fines, and to the fact that the briquettes do not soften under heat. This latter feature is not only of value for domestic and industrial use, but should find application when briquetting before carbonization is desired and also for the briquetting of fines for gas producers. It should also be noted that freezing exposure and the usual mechanical tests have been success-

fully withstood by pulp binder ovoids. The agglomeration of charcoal, ores, salt, soda, catalysts, and chemical mixtures before processing may be cited as other fields of application.

It would be rash and difficult to forecast the extent to which pulp binders may be applicable in the United Stated or Canada, as speaking generally these are not yet briquette-conscious countries. Each case must necessarily be considered upon its merits, but it is obvious that straw and other waste vegetation can be made commercially available especially where water transportation is at hand.

The cost of preparation of pulp binder on a commercial scale will depend to a variable extent upon the cost of procuring the vegetation but the remaining costs may be summarized approximately as follows per dry ton of binder.

Chemical reagents	$5.00
Soda ash	0.60
Labor	1.30
Milling	0.50
Correction for process loss	1.60
General overhead	1.00
	$10.00

Assuming a usage of between 5 and 7 per cent of binder on the dry weight basis and a value of $4 to $6 per ton for the raw vegetation, the cost of the binder would be about 0.90 per ton of briquettes. The cost of briquetting and the cost of a briquetting plant do not differ appreciably from standard practice, and an existing plant can be readily and economically adapted and provided with the necessary drying appliances, which can be operated from the boiler plant, exhaust steam, or waste heat available at the usual type of operating plant.

Assuming the pulp binder conservatively to cost $1.00 and allowing for all overheads, depreciation, etc., it is reasonable to assume that where a total cost for briquetting of $2.00 per ton is commercially permissible the use of this new tool of the fuel economist should be seriously considered.

DISCUSSION

CHAIRMAN PERROTT: I would like to ask Dr. Kerschbaum how he believes that the carbonized product made from lignite would function in our American domestic furnace.

F. P. KERSCHBAUM: Since you ask me about the use in domestic furnaces, I can only tell you what has been the result in Germany. This shows that you have a smokeless, very efficient fuel which does not sag.

For a long time in Germany, this "Grude" has been used, and in the middle part of Germany, it is a general domestic fuel. This new fuel is turning out to have more volatile substance even more suitable for domestic fuel purposes.

CHAIRMAN PERROTT: About what is the specific gravity?

DR. KERSCHBAUM: The specific gravity depends on the volatile used. You get about 0.3 to 0.4.

CHARLES TURNER (61 Cecil Street, Glasgow, Scotland): I would like to ask the temperature of ignition.

DR. KERSCHBAUM: The temperature of ignition, of course, is partly influenced by inorganic substnces. So temperature of ignition will be found to be about 150° to 160°C.

MR. WILBERT J. HUFF (Professor of Gas Engineering, Johns Hopkins University): I thought I caught a statement to the effect that certain heavy chemicals were spread on the grass and so on before fermentation took place. I am not sure I got that correctly, but should like to know possibly what those heavy chemicals are.

MR. ROBERT M. CRAWFORD: I am not competent to discuss this question, because I don't know anything about it. But I made the note myself, when I read it over, that no mention was made whatever of the heavy chemicals sprinkled on this peat. There is no mention in the paper whatever of the nature of those compounds.

I have had time to make a pertinent observation here. You will note the binder cost per ton in briquettes is noted here at 90 cents a ton. If we take our briquetting as we use it in this country, say $15 to $18 per ton, we will find our binder cost, where we use briquetting pitch, will be about 90 cents per ton.

I make the remark because of the caloric value of the binder being used. This pulp binder is definitely stated in the paper to be about half the value of coal, whereas when we use the pitch binder, we can safely assume the caloric value of the pitch is practically the same as the caloric value of the coal.

MR. C. M. BAKER (Engineer, American Paper and Pulp Association, New York): I would like to inquire whether anyone has had experience with using sulphite waste paper in the paper mills, in the briquetting of coal. I believe that it has been so used. The disposal of sulphite paper is a real problem in the paper industry, and we now have a committee working on that problem to endeavor to develop the solutions, and we are looking for outlets for that product.

CHAIRMAN PERROTT: Has anyone had any experience in the use of sulphite waste paper as a briquetting material?

MR. C. J. LENTZ (New Jersey Zinc Company of Pennsylvania): Our company is using that in very large quantities, in anthracite dust and ore, and zinc ore, and it is very successful. Of course, it is a definite cost which we would like to avoid. The cost of sulphite binder per ton of briquettes is 45 to 50 cents. You cannot very well go under that and handle the briquettes to any extent. And we have to dry the briquettes, of course, so that you have all that cost to add on.

MR. BAKER: That is where the material is right close at hand.

MR. LENTZ: No, we get it shipped in.

MR. W. P. PUTNAM (Detroit Testing, Ltd., Detroit): I would like to ask this last speaker if the use of this sulphite pitch in any way makes a briquette waterproof or otherwise.

MR. LENTZ: No, it is not waterproof. The sulphite binder, of course, is supposed to be a rather complex, woody extract. Even after briquetting and drying at temperature as high as say 150°C., it is still water soluble. You cannot store it out in the open.

MR. A. W. GAUGER (Director, Division of Mines and Mining Experiments, University of Nortn Dakota): If I am not mistaken, some years ago the sulphite pitch was tried in the Bureau of Mines, and I believe it was also tried at the University of North Dakota.

Unfortunately, however, the briquettes are not weatherproof and require additional treatment in order to make them weatherproof. You see the difficulty with lignite now is not in weatherproofing. When you produce a briquette, you must produce a briquette that will not slack when standing in weather and also not slack in the fire. If it slacks in the fire the fine coals slip through the grates.

MR. C. J. GOODWIN AND DR. G. N. WHITE write as follows in reply to the above discussion:

Our contribution to the Conference was more in the nature of a brief note reporting progress than a complete presentation of the properties, preparation and use of pulp binders, and it will be appreciated that a full exposition of the subject would take up too much valuable space. As regards the proeess, additional information will be found in English Patent Specification No. 244517 and the corresponding United States application is due for acceptance at a very early date. Patents have been granted in some twenty other countries, including Germany, but of course the details given therein do not represent the full development of the processes at the present time. As regards the heavy chemicals which are used as a bacterial food, these are substantially of the nature of a mixed fertilizer, containing nitrogen, phosphate, etc., in suitable proportions. The exact composition is not as a rule disclosed, but leading chemical manufacturers in all civilized countries are in a position to supply on contract at stable prices.

It is necessary to correct Mr. Crawford's remarks, because peat is only used in most exceptional circumstances in the preparation of this binder. Mr. Crawford also gives the binder cost, when using briquetting pitch as about 90 cents per ton when the price of pitch is $15 to $18 per ton. It is most exceptional to find in actual practical manufacture that the percentage of pitch required for briquetting anthracite is less than 8 per cent and when a smaller usage is possible, then equally it is possible to use proportionately less of the pulp binder. The corresponding figure for binder costs when using briquetting pitch is therefore about $1.30 as compared with 90 cents for pulp binder. Allowing for the fact that the calorific value of pitch is higher, and that there is a small percentage of ash in the pulp binder which is not present in pitch it is reasonable to assume as stated in our paper that a pulp binder cost of $1 per ton of briquettes is commercially permissible, and moreover no allowance has been made in this for the commercial value of *smokelessness* which is by no means negligible.

Proposals to use sulphite pitch for briquetting are horticulturally speaking, a "hardy annual." These proposals are revived at frequent intervals and a great deal of money and time has been spent and in many cases lost, in the erection of plants based on the use of this material. Sulphite liquor makes an excellent binder, and an excellent briquette provided the latter is baked under the correct temperature conditions. Unfortunately if the correct temperature is not attained, or if it is exceeded, the briquettes become useless for commercial purposes. The permissible temperature range is very small, and this is one of the principal differences between the heat treatment required for pulp binder briquettes and those made with sulphite liquor, the latter thus requiring an oven of difficult and expensive design.

Pulp binder ovoids or briquettes merely require trying to harden them, and at a temperature of about 120°C. To impart all the desirable properties there is no need to maintain exact temperature regulation, provided 200°C. is not exceeded. On the other hand, with sulphite liquor, a considerably higher temperature and exact regulation within about 2 per cent is necessary, and these two factors represent additional fuel cost, and heavy capital expenditure on specially designed furnaces. In certain special localities, and under favorable conditions, the use of sulphite liquor may be justified, but we believe it is common knowledge that both in Europe and in America several plants have proved to be failures, and it is only recently that improvements have been effected particularly as regards the admixture with the sulphite liquor of other ingredients which may enable that material to be considered under circumstances which are not exceptional. Sulphite liquor, moreover, is only available as a rule in places which are remote from the fuel to be briquetted, so that the cost of sulphite binder per ton of briquettes is seldom competitive. We do not in any way claim that pulp binder is a universal binder, in fact it has been stated in our paper that at any rate for bituminous fines, pitch is preferable when commercially available, as it would be in industrialized countries. On the other hand, for semi-coke and anthracite, and particularly in localities where pitch is not a feasible proposition, there would seem to be no alternative to a smokeless binder such as we have described, and which,

whilst not possessing all the ideal properties enables a satisfactory and readily salable anthracite substitute to be marketed for domestic and commercial use.

We notice that Mr. Gauger has already referred to the fact that sulphite pitch briquettes require additional treatment such as baking, in order to make them stand up in the weather, and we would again emphasize that pulp binder ovoids do not slack either in the weather or in the fire. When burnt, pulp binder ovoids do not even soften in the way that pitch bound ovoids do, and if left undisturbed the ultimate result in a slow combustion stove is a shell of ash which falls to powder when disturbed after the fire is out.

Finally, we would mention that in submitting some very rough figures in regard to costs as a guide, we have endeavored to be conservative and entirely on the safe side, and it must be obvious that a figure of $4 to $6 per ton for the raw vegatation can often be improved upon. We would recommend to universities possessing fuel departments, the carrying out of experiments with pulp binder, and for this purpose we shall be very glad to supply at cost, either suitable quantities of binder, or of the necessary chemicals, together with instructions for preparation and manufacture.

THE CONVERSION OF SLACK COAL AND FINES INTO LUMPY SMOKELESS FUEL—LOW TEMPERATURE COKE—BY THE C.T.G. PROCESS

By Josef Plassmann

Director, Chemisch-Technische Gesellschaft, Duisburg, Germany

Read by Hans Sieg

Of late years numerous processes have been developed in the field of low temperature carbonization, the practical experimenting with which has brought us much nearer to the solution of this problem. The experience gained has taught us what factors are essential to produce primary tar and gas of a high grade combined with a good yield as well as a usable low temperature coke. At all events, it provides a foundation, both in theory and in practice, for the future development of low temperature carbonization.

At the present stage, it is naturally impossible to predict which process will finally prove to be the most advantageous from a technical and commercial standpoint, but it may safely be said that those processes will hold their ground in the future which combined with a low cost of operation yield a high grade smokeless fuel as the main product, whilst producing at the same time tar and gas in the right quantity and quality. Guided by these considerations, the Chemisch-Technische Gesellschaft, hereinafter referred to as the "C.T.G." has aimed at developing a low temperature carbonization process that will yield an easily marketable smokeless fuel which should be strong and of large size. The tar obtained should be practically free from dust and ash and should be easily separated from the liquor, while the gas should have the maximum possible heating value. In order to obtain these results, the C.T.G. circular cell oven was designed, which produces a coherent lumpy coke owing to the coal being tightly packed and at rest throughout the process of carbonization, while at the same time the operation is continuous. The other requirements, above-mentioned, are likewise fulfilled as a primary tar is obtained which is almost entirely free from dust and ash as well as a gas of great calorific value. The following is a detailed description of the development of the C.T.G. low temperature carbonization process and the results obtained.

Figure 1 shows, in plan and elevation, the general scheme of the design of the circular cell oven. The internal structure comprises a

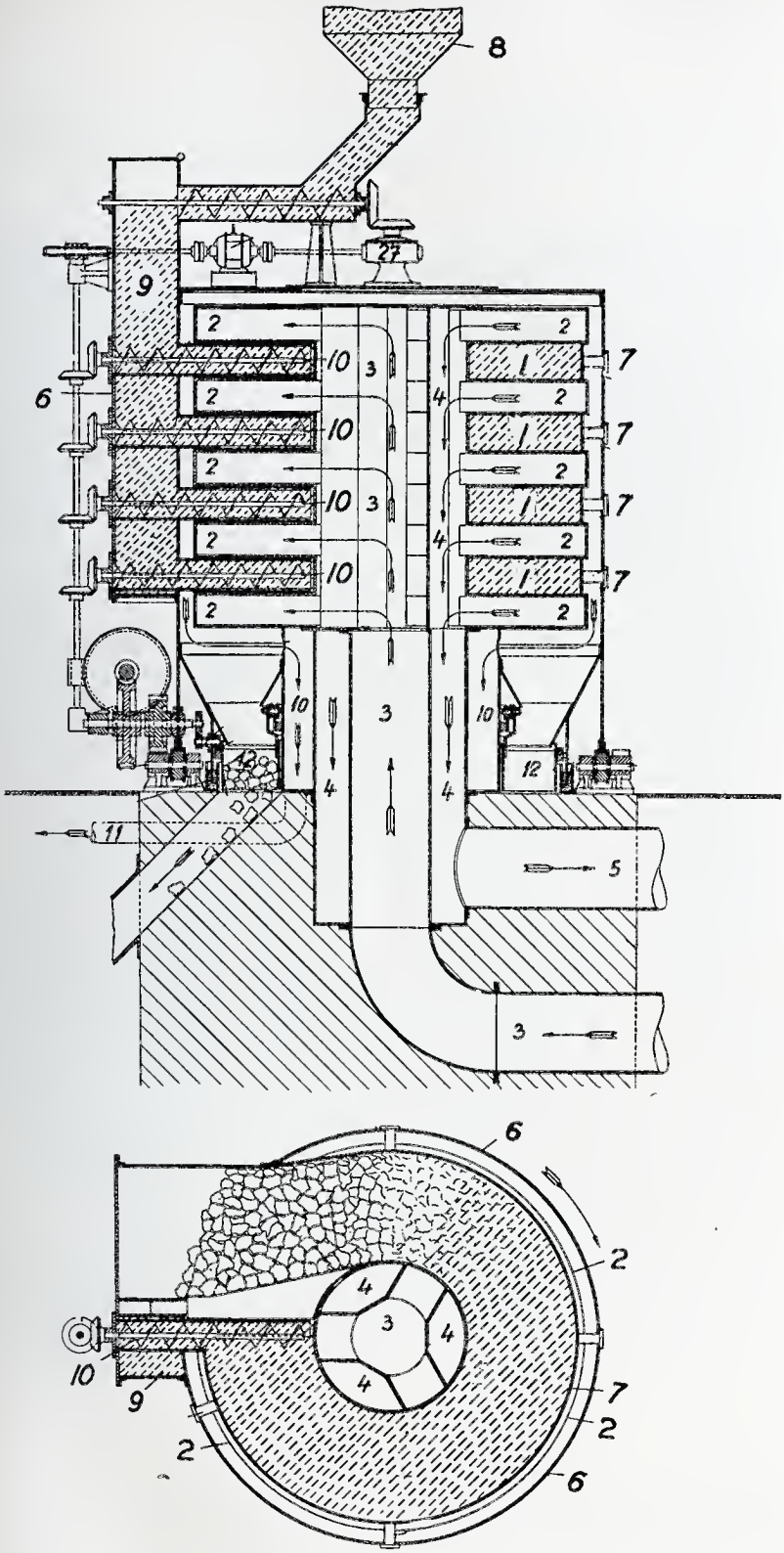

Fig. 1. Sectional Plan and Elevation Showing Arrangement of the C.T.G Oven

series of horizontal annular heating chambers *2* superimposed one above the other, firmly screwed together, and separated by the coking chambers *1*. Coal, especially in the shape of fines and slacks, being but a poor conductor of heat, the height of the coking chambers was reduced to a minimum in order to secure a short period of carbonization and consequently a large throughput. The center of the structure is occupied by the ducts for the heating gases, which enter the oven through the duct *3*. Hence they pass in all directions into the heating chambers which are provided with guides and then pass out of the oven through the ducts *4* and the pipe *5*. Owing to the central arrangement of the ducts for the heating gases, the loss of heat by radiation and conduction is very small resulting in the attainment of a high degree of thermal efficiency.

The coking chambers are closed internally and are charged and discharged at the external periphery. The shell *6* of the oven rests on three pairs of rollers and revolves slowly around the coking chambers in the direction of the arrow. It carries the coal-feeding and coke-discharging gear together with the closing bands *7* for the coking chambers. In this way the coal can be fed into the chambers under pressure without dropping out.

The coal passes from a bunker *8* placed above the oven into a shoot *9* on the shell, from where it is fed by means of the conveyor worms *10* into the chambers where it is deposited under pressure. As the worms revolve slowly around the internal structure of the oven owing to the rotation of the shell, the coal remains absolutely at rest during the period of carbonization. After the coking process is over, the ploughs located in front of the worms and likewise attached to the shell, discharge the coke which drops through special shoots on to a conveyor wheel *12* and is carried thereby to a gas-tight discharging device. The gases first pass from the coking chambers to the space inside the shell, which is sealed from the outer air by means of an annular water pan. Hence they pass into an annular reservoir at the bottom of the oven and are sucked off through the duct *11* to the condensing and gas washing plant.

The shell is made to revolve at a predetermined rate in accordance with the nature of the coal under treatment and the requisite time of carbonization. The number of revolutions of the feeding worms and consequently the density of the charge of coal in the coking chambers is likewise adjusted in accordance with the physical properties of the coal put through.

After the various materials and constructional details most suitable for the building of such an oven had been thoroughly investigated,

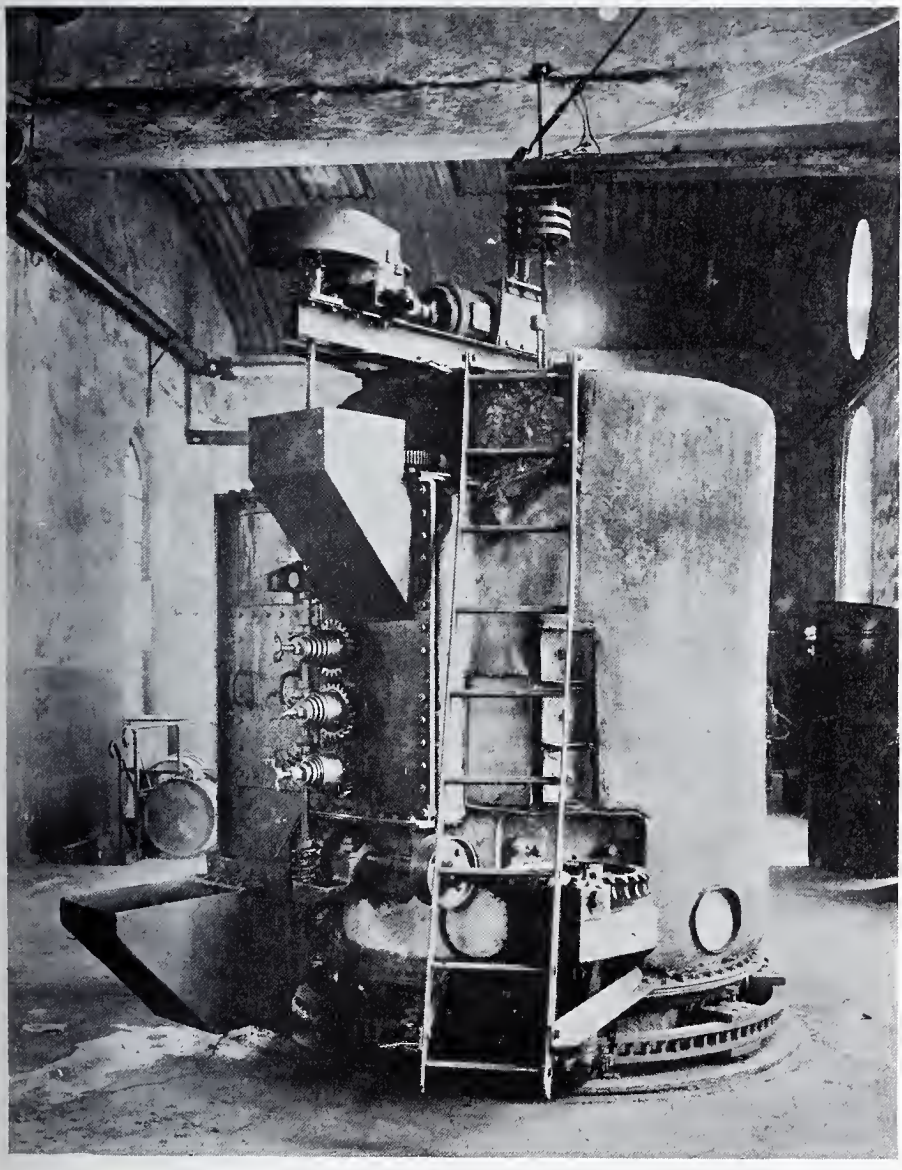

FIG. 2. EXPERIMENTAL OVEN OF A CAPACITY OF 1 TON OF COAL

a technical experimental oven was first constructed which was put into operation in September, 1925. It entirely justified all anticipations. From Figure 2 it will be seen that this experimental oven has

3 coking chambers capable of a throughput of 1 ton of coal in 24 hours. The outer shell of the oven, driven by a small motor of 0.5 kw.

FIG. 3. CENTRAL STRUCTURE OF THE EXPERIMENTAL OVEN AFTER CONTINUOUS OPERATION DURING SEVEN MONTHS

placed on the top of the shell revolves once in seven and a quarter hours in accordance with the carbonization time required by the

charge of coal which, in this case, is 12 cm. thick. The coal is fed into the coal shoot by hand, while the low temperature coke is discharged through the provisional water gate. It is interesting to note that the internal structure which is made of mild steel plates riveted together, has given no trouble and shown no signs of distortion or wear in spite of considerable deliberate overloading. It has been possible to learn some very interesting facts in experimenting with this oven regarding the strength of mild steel at 600°C. Figure 3 shows the internal structure of the oven after it had been in continuous operation for a period of 7 months, the internal structure having been only cleaned with a hand-brush.

FIG. 4. SPECIMENS OF COAL DUST AND SMOKELESS FUEL PRODUCED BY THE ELECTRICAL RETORT AND THE EXPERIMENTAL OVEN

With the aid of this experimental oven, which works exactly like a full size unit, it is possible to test the coking properties of any kind of coal within the shortest possible time and at a minimum cost. In fact, ever since its erection in September 1925, this oven has been in uninterrupted operation for the purpose of testing various kinds of home and foreign coal, 3 to 5 tons being in each case required for such a test. The experience gained, it need hardly be said, has been of the greatest value.

Moreover, the C.T.G. has made a simple, but very useful laboratory retort for testing coal of any description if only very small quantities are available, a test of 4 or 5 kg. being sufficient to ascertain the coking properties of the coal either alone or mixed with other kinds.

The experiments have shown that the low temperature coke gained in this laboratory retort is always at least equalled in quality and

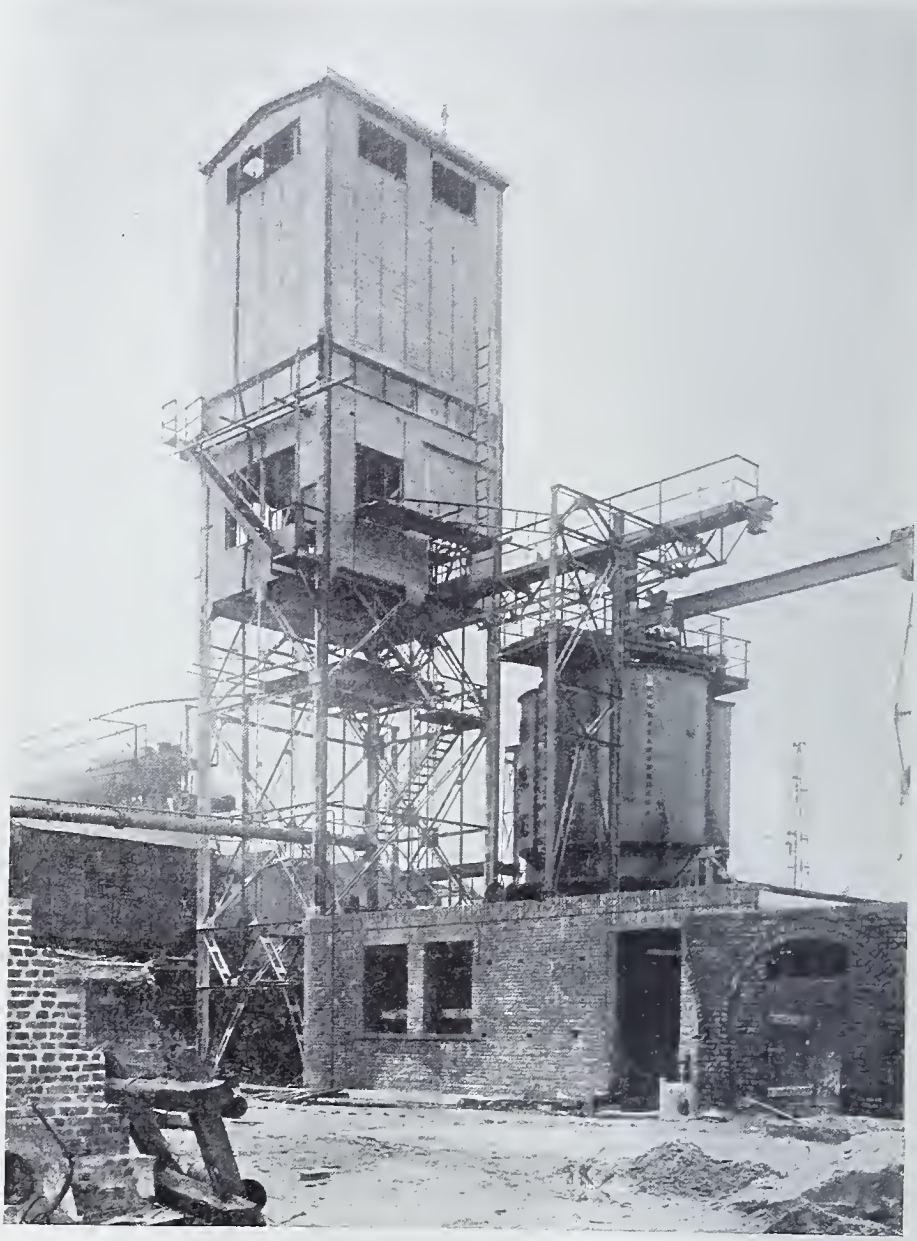

FIG. 5. 50-TON C.T.G. OVEN AND COAL BUNKER

usually surpassed by the coke of the 1 ton experimental oven. Figure 4 shows such a comparison. On the left one sees the fines of 0 to 1

mm. size subjected to the test; in the middle the low temperature coke produced by the laboratory retort from 500 grams of this coal, and on the right the coke obtained from the same coal in the technical experimental oven. As seen from the picture, the coke produced by the retort shows a faint tar seam, whereas that produced by the experimental oven has an entirely homogeneous structure throughout.

On the strength of the favorable results obtained with the small experimental oven, a large furnace was erected at the Prosper II

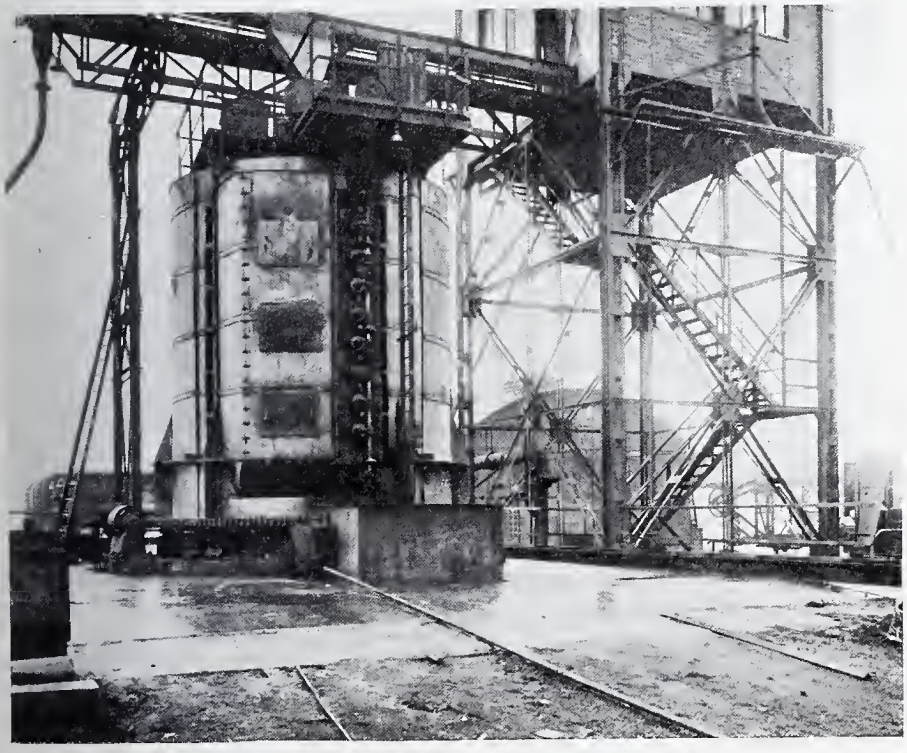

FIG. 6. 50-TON C.T.G. OVEN IN OPERATION

colliery belonging to the "Rheinische Stahlwerke" in the Rheno-Westphalian district, Germany, which has been successfully in operation since the end of 1927. This oven has 19 heating chambers of a diameter of 3.9 meters. As each pair of heating chambers forms one coking chamber, the furnace has 18 coking chambers in all. The height of the several coking chambers and consequently the thickness of the layer of coal contained in the same is but 10 cm. thus reducing the period of carbonization to approximately 5 hours. The net carbonizing volume of this furnace, i.e., the contents of

the 18 coking chambers, equals 12 cubic meters per revolution, corresponding to a throughput of about 50 tons of coal of the usual specific gravity in 24 hours. The external diameter of the furnace inclusive of the insulating material amounts to approximately 4.5 meters, the total height being 6 meters.

Figure 5 shows the furnace immediately before the erection was completed and before lagging against loss of heat by conduction and radiation.

Figure 6 shows the complete furnace in operation.

In this furnace aspirated fines of a size from 0 to 1 mm. are carbonized. They are conveyed through pipes by means of compressed air from the pithead to the two bunkers shown in Figure 5. From this point the coal is conveyed by a worm to the distributing bunker, which is centrally located on the upper platform of the furnace. Two worms revolving with the shell take the coal from the distributing bunker and feed the two coal shoots equally. Here the conveying worms take the coal and convey it continuously under pressure to the several coking chambers. The finished coke is extracted from chambers by means of the ploughs and drops through the two coke shoots on to the conveyor wheel located in the lower part of the furnace until it finally reaches the coke discharge.

The heating of the coking chambers takes place by a circulatory system, the heating gases being constantly circulated through the piping by a fan and re-heated by the addition of hot combustion gases before they re-enter the furnace. This mode of heating was first of all thoroughly put to the test in the experimental oven during a period of several months and has given entire satisfaction both here and in the large furnace. The difficulty of finding the most suitable material for the circulating fan which operates at a temperature of 600° to 650°C. has been satisfactorily solved. After many months of work the constructional parts in contact with the heating gas have not shown the least trace of corrosion or distortion. The thermal efficiency of the heating is remarkably high owing to the comparatively small cooling surface of the heating system. In any case, the heat consumption per kilogram of carbonized coal is considerably smaller than is the case with any other known process. Another great advantage of the heating system adopted is the fact that the copious sub-division of the flow of the heating gas and the high speed achieves practically the same coking temperature in all parts of the 18 coking chambers. In this way the low temperature

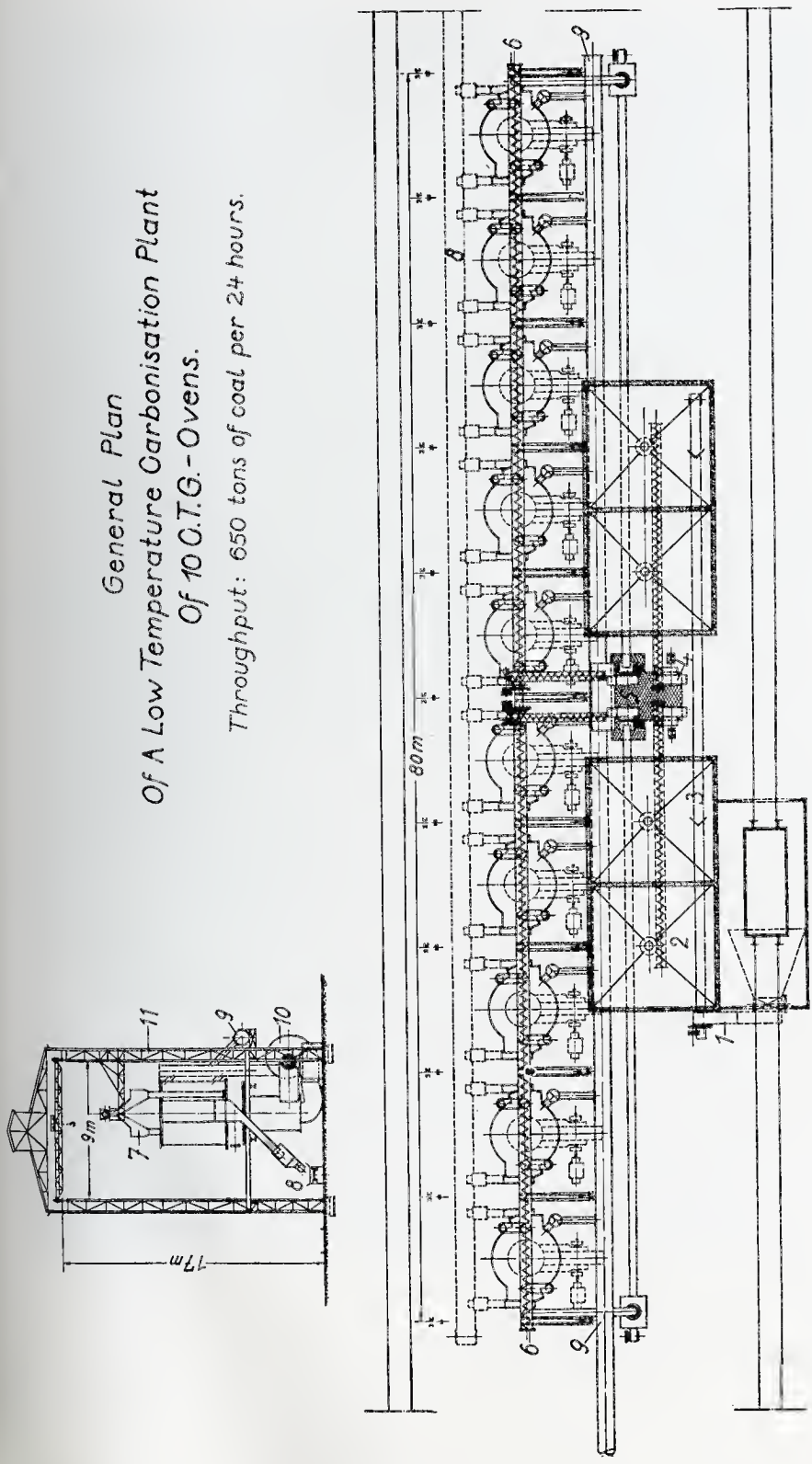

FIG. 7. GENERAL PLAN OF A LOW TEMPERATURE CARBONIZATION PLANT OF 10 C.T.G. OVENS

coke in each of the coking chambers shows the same structure and hardness.

Figure 7 shows a layout of a large plant of 10 annular cell furnaces for a total throughput of 650 tons in 24 hours, the coal being supplied by rail. A coal tip discharges the cars into an elevator pit from where a paternoster elevator *1* conveys the coal to a band *3* located above the bunkers *2*. By means of adjustable scrapers the coal can be taken off at different places along the band into the various bunkers which, in the plant in question, number four of a capacity that largely depends on local conditions of coal supply. As is indicated in the plan, the coal may, if necessary, be conveyed by band or worm to a mixing plant *4*, which would most conveniently be placed in the middle of the battery of ovens. Two paternoster elevators *5* then pass the coal on to the worms *6* located above the battery which convey it to the different furnaces. To increase the throughput the coal may be previously dried by means of waste gases during the transport. Special intermediate bunkers *7* are provided on the upper platforms of the furnaces in order to regulate the coal supply in case the capacity of any of the furnaces should change.

The low temperature coke is transported with the aid of a conveyor band *8* running along the battery direct to the dressing plant or loading wharf. Likewise a central pipe *9* is provided for conveying the low temperature gases to the condensing and washing plant. The circulating fans *10* together with the remaining accessories are located directly beneath the furnace and operating floor so that but a small space is required for the whole plant. In fact, the plant of 10 furnaces in question including the coke conveying band and central gas piping would only require an area of 80 by 9 meters, i.e., 720 square meters. To instal the furnaces in a closed building would not only be superfluous but even inconvenient. In the plan a roof is provided, the trusses of which rest on the supports *11* of the crane track. The weather-side of the plant may be protected by a thin wall. The height of the crane track is about 17 meters.

Due to the favorable results obtained by the C.T.G. low temperature carbonization, a large plant on this principle is to be erected on the Thames near London. Three large furnaces of 65 tons daily throughput each are already in course of construction. This plant is to be gradually enlarged later on.

In order to be able to study the carbonizing properties of British

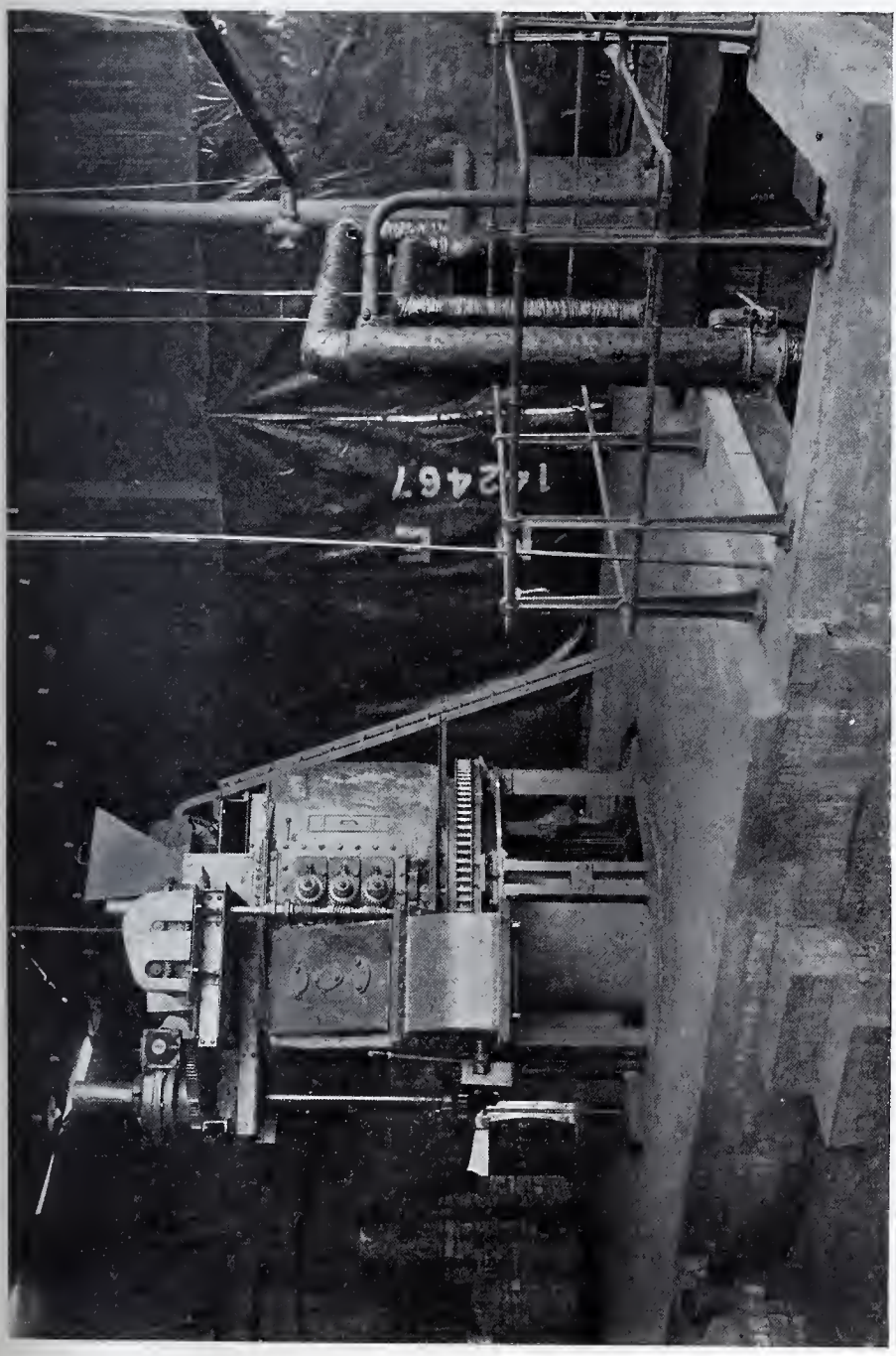

FIG. 8. EXPERIMENTAL OVEN OF A CAPACITY OF 2½ TONS OF COAL

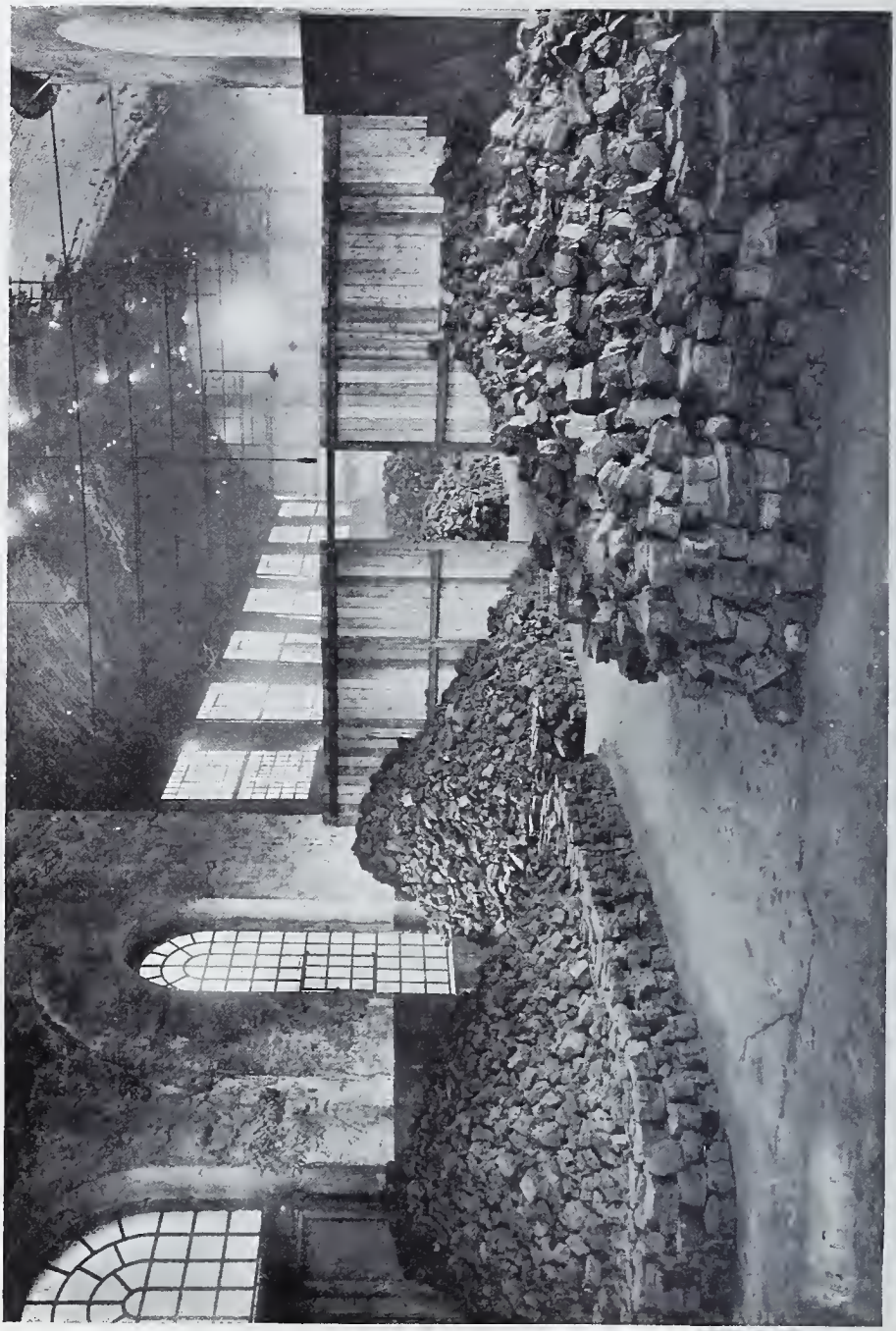

Fig. 9. Smokeless Fuel from the 1-ton Experimental Oven

coal on the spot, an experimental oven of a daily throughput of 2.5 tons was put into operation in England in June, 1928. In this way a considerable amount of experience will be collected about the most suitable use and mixture of the various kinds of British coal. Figure 8 shows the external structure of this 2.5-ton oven, which differs only immaterially from the 1 ton experimental oven built in 1925 so that it would seem unnecessary to enter into details.

FIG. 10. SMOKELESS FUEL FROM THE 50-TON C.T.G. OVEN

After this brief description of the C.T.G. carbonizing process and its constructive realization up to the present, we may now proceed to discuss the various products of the furnaces. As the coal under treatment remains absolutely stationary during the whole process, fines and slacks may unhesitatingly be used as starting material for the low temperature coke without danger of any considerable loading of the outflowing gases with dust. Of course, a coal of a size up to 15 mm. can also be safely carbonized in the furnace of the present design. The large furnace in operation on the premises of the "Rheinische

Fig. 11. Specimens of Smokeless Fuel

Stahlwerke" carbonizes, as mentioned before, aspirated fines of a grading of 0 to 1 mm. This kind of coal can only be described as a low grade coal, since it has to be removed from the coking coal on account of its high ash content and many other objectionable properties which render its treatment by a high temperature carbonization process very difficult. Yet it is possible to produce in the C.T.G. furnace even from this inferior material a low temperature coke of

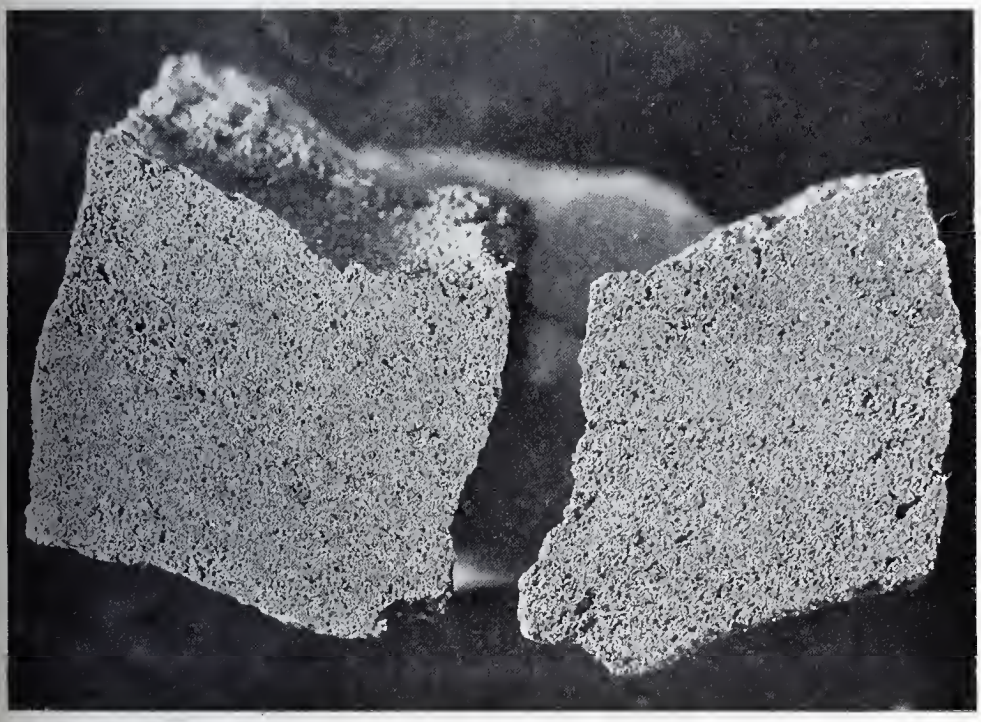

FIG. 12. TEXTURE OF SMOKELESS FUEL MADE OF COAL DUST FROM THE PROSPER MINES BY THE C.T.G. PROCESS

(Natural scale)

excellent quality, as the following pictures will show. It goes without saying that the washed coking coal will yield the same or a still higher grade coke. By mixing coals of different properties the scope of the C.T.G. furnace can be considerably extended. We succeeded, for instance, in producing a good low temperature coke by mixing 50 per cent of anthracite duff with 50 per cent of highly-caking coal. To obtain good results from a similar mixture it is of course necessary to make preliminary investigations regarding the physical properties

of the several kinds of coal. The most important thing is to get a clear insight into the process of distillation during the coking operation and to ascertain the caking capacity of the coal.

Figure 9 shows samples of coke produced by the 1 ton experimental oven. These samples were obtained from different coals of the Rheno-Westphalian district and partly from mixtures of strongly caking coal with coal of little or no caking capacity at all. The

FIG. 13. TEXTURE OF HIGH TEMPERATURE COKE MADE OF WASHED COAL FROM THE PROSPER MINES

(Natural scale)

picture shows the splendid appearance of the coke. The thickness of the lumps of coke depends upon the height of the coking chambers of the oven. Figure 10 shows coke produced by the first large furnace mentioned before, from which we see that here also the coke is of exactly the same good grade. In Figure 11 some lumps of coke are represented that clearly show its uniform and coherent structure. The structure of the low temperature coke is still better shown in Figure 12, which represents a polished section of the coke, showing its structure in natural size. By way of comparison Figure 13 shows

the structure of the blast furnace coke produced from the same coal. The comparison is all the more in favor of the low temperature coke, since the blast furnace coke is produced from washed eoal, whereas the low temperature coke was made from the mere waste slacks of the very same description of coal. Both photographs were taken by Professor Dolch of the University of Halle, and were published in No. 10 of the issue of *Glückauf* of March 10, 1928. Regarding these pictures Dr. Dolch writes as follows: "The low temperature coke produced by the Colliery Prosper in a C.T.G. furnace shows most excellent characteristics; probably the extraordinarily fine structure of the coke was due to the peculiarly favorable properties of the coal used. The singularly hard low temperature coke, which is of great compressive strength shows a much more uniform and coherent structure than the blast furnace coke produced by the same coal."

Of course, a similarly homogeneous coke can only be turned out if the heat penetrates the charge in exactly the same way from above and below so that the temperature in the different parts of the charge is about the same. This ideal state is the more easily realized as the charge is fed into the coking chamber under pressure and consequently deposited so closely together as not to leave room for the slightest interstices. In accordance with the preceding pictures of the structure of the coke, investigations have shown that the low temperature coke possesses a great hardness and a high specific compressive strength. In dressing low temperature eoke with the aid of coke erushers, the coke can be crushed to any grading so that any marketable size can be readily turned out. The results of the large plant at the Prosper Colliery have conclusively proved that losses due to disintegration and abrasion are extraordinarily small during the process of crushing.

Table I shows the results of the investigations by Dr. Franz Fischer of the Kaiser Wilhelm Institute for Coal Research. The low temperature coke in question was obtained from low grade aspirated coal dust, having an ash content of 13.1 per cent.

The low temperature coke of the C.T.G. furnace contains 8 to 10 per cent volatile matter and burns therefore with a considerable volume of flame, which is perfectly smokeless. Consequently, it constitutes the most suitable substitute for anthracite coal. Since any grading can be readily obtained, this low temperature coke is well suited for use as a domestic fuel, e.g., for central heating, kitchen stoves and in the smallest grading of some 10 to 20 mm. for stoves

built on the continuous burning principle. The low temperature coke being very lumpy, of high compressive strength and having only a slight tendency towards disintegration and abrasion, its use for metallurgical purposes presents great possibilities so long as due regard is paid to the high degree of reactivity and the fact that its temperature of ignition is about 400°C.

TABLE I

ANALYSIS OF LOW TEMPERATURE COKE

	RAW COKE	DRY COKE	PURE COKE
Moisture, per cent	2.6		
Ash, per cent	15.6	16	
Volatile constituents, per cent	9.4	7	8.3
Coke, per cent	90.6	93	91.7
Calorific value, cal. per kg	6,596	6,788	8,081
Combustion heat, cal. per kg	6,740	6,920	8,238
Carbon, per cent	72.7	74.6	88.8
Hydrogen, per cent	2.3	2.4	2.9
Sulphur, per cent	1.3	1.3	1.5

Melting point of the ash 1310°C.

TABLE II

ANALYSIS OF THE CRUDE OIL

	CRUDE OIL	WATER-FREE OIL
Water, per cent	0.6	
Ash, per cent	0.02	0.02
Dust (insoluble in benzol), per cent	0.21	0.21
Specific gravity at 20°C	0.995	
Flame point, degrees C	44	
Burning point, degrees C	53	
Ignition point, degrees C	580	
Viscosity (Engler) at 20°C	2.94	
Sulphur, per cent	1	1
Carbon, per cent	85	85.5
Hydrogen, per cent	8.8	8.9
Phenols, per cent	20	20.1
Combustion heat, cal. per kg	9,572	9,630
Calorific value, cal. per kg	9,091	9,149

Table II shows the characteristics of the primary tar or crude oil produced by the coking process. The figures given are those obtained by the Kaiser Wilhelm Institute for Coal Research.

Practically speaking, the C.T.G. process turns out twice as much oil as is obtained in a coke oven.

It is interesting to know that the crude oil contains but 0.02 per cent ash and 0.5 per cent dust, which figures are far above 1 per cent with all other processes. This almost dust and ash-free composition of the crude oil and the firm lumpy shape of the low temperature coke are only due to the perfectly stationary condition of the coal during the coking process.

The crude oil as produced by the furnace has proved itself to be eminently suitable for use as a fuel without further refining, and has given excellent results as s Diesel engine oil.

The composition of the low temperature gas appears from the average analysis given in Table III.

TABLE III

ANALYSIS OF LOW TEMPERATURE GAS

	PER CENT
H_2	25.3
CH_4	49.8
C_2H_6	8.6
C_nH_m	3.4
CO	1.3
CO_2	4.2
O_2	0.1
N_2	7.3
	100.0

This analysis corresponds to a gross calorific value of about 7100 cal./cbm_n and a net calorific value of 6400 cal./cbm_n.

This high grade low temperature gas can be used to advantage for the enrichment of town gas supply, while the ovens themselves may be heated with lower grade gases.

The solution of the problem of turning the by-products to the greatest advantage is no doubt only in its first stage. The main reason is that so far large quantities of lumpy low temperature coke, crude oil and low temperature gas have not been continuously available. However, investigations have meanwhile shown that the future has some new and valuable possibilities in store. When these are realized the present commercial success of the Low Temperature Carbonization process described above will be considerably increased and a much higher place will be secured for the low temperature carbonization of coal in the fuel industry of the world.

CARBONIZATION OF BRIQUETS AT LOW TEMPERATURE BY SUPERHEATED STEAM

By Paul Weiss

Honorary Director of Mines at the Ministry of Public Works, Consulting Engineer of the Compagnie des Mines de Vicoigne, Noeux, et Drocourt

Read by Jacques Weiss

I. Fundamental Importance of the Value of the Solid Residue from Carbonization

In its important plants, which have been in operation since 1926 on a commercial scale, the Compagnie des Mines de Vicoigne, Noeux, et Drocourt has made a contribution to the industry of carbonization of coal at low temperature.

The common opinion is that carbonization at low temperature should not be considered if it does not offer opportunity for a considerable recovery of by-products. As was cleverly said by a member of the Conference at Pittsburgh in November, 1926, every process of carbonization at low temperature is immediately criticized unless it gives:

1. A solid residue comparable with the best existing anthracites.
2. Oils superior to the best crude Pennsylvania petroleum.
3. A gas so rich that the sale of it yields extraordinary profits to gas companies.

Of course the Compagnie V. N. D. hopes that it and others will one day reach these results. But at the moment it has shown that it is enough to realize one of the conditions enunciated to obtain a paying industrial development.

From the commencement of its studies, which date back to 1919, it has striven to make the solid residue from carbonization of maximum value. It has not for that reason neglected the recovery of oil, tar, and gas; but it has not attached thereto the immediate fundamental importance which is in general attributed to them. Improvements in this field will come in due time.

The manufacture of semi-coke of perfect quality is so much the more necessary as the continuous development of domestic furnaces demands the uses of special fuels, which will burn slowly without

smoke and give an ash only slightly sintered without production of clinker. The point of fusion of the ash should not be below 1300°C., and the content of ash should not exceed 7 to 8 per cent. But for the utilization of artificial fuels to become general, it is necessary that their physical characteristics correspond to those of natural fuels. The fuels should be of great hardness to resist transport and handling without dust and they should not disintegrate from weather.

II. Principle of Industrial Production

The principle of the manufacture of smokeless fuels in use at the Mines de Vicoigne, Noeux, et Drocourt, consists in briquetting fine coal into ovoid briquets with pitch or with asphalt as binder, then putting these briquets into a series of fixed retorts, and heating these retorts progressively and systematically with steam superheated to about 650°C.

The steam is then condensed so as to allow the recovery of the oil and primary tar, the gas, and the greater portion of the binder used for the briquetting.

Preparatory studies had made possible a calculation that the capital to be invested would be comparable (although slightly less) to that for a battery of coke ovens of the same capacity, and that the cost of conversion would amount to $3.00 or $3.50 per ton of salable briquets.

This calculation applied to a production of 300 to 400 tons per day, starting with coal containing less than 18 per cent volatile matter, and including all costs for labor, maintenance, repairs, power, amortization, etc. It likewise took into account the recovery of by-products.

Practice has confirmed these estimates and one may be certain of manufacturing a fuel in sized pieces without having the cost of production exceed by more than $3.50, that of the fine coal employed.

At the plants of the Compagnie de Vicoigne, Noeux, et Drocourt, the washed fine coal is dried by means of waste heat, and briquetted with pitch or liquid asphalt in ordinary roll presses. The briquets, of ovoid form, have a weight of 45 or 65 grams in the raw condition. At Noeux there are principally used coals of 13 to 14 per cent volatile matter and 16 per cent ash.

On leaving the presses the briquets are taken by a wire cloth conveyor to the carbonization retorts. Each retort contains 20 tons and the group of retorts is heated systematically by superheated steam.

Steam has been chosen by preference as the heating fluid because it does not react on the coal at the temperatures used; it has a very high specific heat; and it can be separated easily and completely from the volatile hydrocarbon products which are carried off with it.

The objection has been raised that the heat efficiency of the plant is likely to be bad, because only the sensible heat of the steam is used and since the latent heat of vaporization is entirely lost.

At the Compagnie de Vicoigne, Noeux, et Drocourt, this serious disadvantage has been avoided by producing steam at high pressure and expanding it first in turbines to produce electric power.

The steam is then superheated in special superheaters before entering the carbonization apparatus.

The cost of the steam as heating fluid is thus reduced to extremely low figures which permit its general use.

The product has received the name "Anthracine." It is sold in the form of briquets carrying a double groove, and the public has given it an excellent reception.

III. Description and Operation of the First Plant at Noeux

The first carbonization plant at Noeux comprises eight cylindrical retorts of steel plate, arranged regularly around a central distributor composed of a cock with multiple openings.

These retorts have a diameter of 3.5 meters and a height of 5.5 meters. For changing and discharging they are equipped with doors, the joint being made of special woven fabric. The mass of briquets is supported in each retort by rings of special form. These rings are arranged in such way that the pressure exerted on the briquets at the different levels of the retort does not exceed the permissible limits, so that there is no danger of deforming the briquets during their softening.

Furthermore, these rings reduce breakage and the formation of waste, which would be considerable if the briquets dropped into the retort with a free fall.

Each retort is provided with an arrangement which, for a given position of the central valve, allows the delivery of the steam either above or below. This reversal of direction of circulation is for the purpose of reducing the disadvantage, both as to uniformity of heating and consequently as to the content of volatile matter, which results from a great height of charge, the latter involving an appreciaable difference in temperature between the top and bottom of the retort.

Pyrometers, whose indications are read at a central board, make it possible to follow the changes of temperature at the bottom, middle and top of the retorts.

The passages provided in the plug and the casing of the central distributor are arranged in such a way as to allow the cooling of the briquets before their discharge. Due to this arrangement, the briquets to be cooled can receive steam taken from the outlet of a primary condenser and stripped of the less volatile of the products, with which it was loaded (pitch and heavy tar). This steam is delivered by a compressor first into the two retorts to be cooled and then into the two retorts which have just been placed in circuit. It gives up to these latter the greater part of the heat which it has taken from the preceding retorts. Thus a considerable amount of recovered heat is utilized for carbonization while at the same time the carbonized products are cooled slowly.

Since damage appeared after a time in the central distributor and in its hydraulic jack, another arrangement has been constructed to obtain the desired result by means of values specially designed to operate positively at high temperatures on steam loaded with pitch and tar.

It is hardly necessary to add that the retorts, the distributing arrangement, and the pipes are very carefully lagged.

To complete this description let us follow the course taken by the briquets leaving one of the presses, of 10 tons per hour capacity, which produce them. By discharge onto a large conveyor of wire cloth, whose speed is quite low, they are given time to cool and to acquire resistance to movement when this conveyor dumps them into the buckets of an elevator which lifts them to the top of the retorts. There they are received by a circular conveyor which feeds at will any one of the eight retorts by means of scrapers and suitable troughs. Their fall is moderate by the rings which likewise limit the pressure exerted upon them by the following briquets.

After charging, the retort is closed, and introduced into the circuit by turning the distributing cock one-eighth of a turn or by opening the proper valves.

The briquets then receive steam which has passed through three retorts in which it has lost a great part of its sensible heat. They receive at the same time the steam which has been used to cool the briquets which are to be discharged after the following rotation of the valve.

At the end of a definite time, which varies according to the nature of the coal treated, a new manipulation of the valve causes the retort under consideration to progress forward in the circuit. The temperature increases regularly and progressively, and the briquet gives up the volatile matter of the binder and of the coal of which it is formed.

To finish the carbonization, the retort then passes into the phase of high heat, during which it meets steam coming directly from the superheaters.

The four phases are equal, and their duration is strictly determined by the nature of the coal and of the binder. The last phase is marked by a reversal of the direction of circulation of the steam, the purpose of which is, as we have seen, to reduce the effect of the more or less great height occupied by the briquets in the retorts. It is seen at once that by control of the rate of rotation of the cock and of the amount of steam it is possible to carry out a heating as progressive as wished.

The carbonized briquets are then cooled by that steam which has first given up its sensible heat in the four first retorts under heat and has then passed through the primary condenser in which the less volatile of the products of carbonization are deposited. Following this condenser it is compressed anew by a compressor.

On discharging, the briquets are run into a pan filled with water which is located under the eight retorts, over a grid-work through which is intended to remove the dust. They are picked up by a conveyor in which they are still further wetted and are then discharged into a drum which separates the broken pieces. Finally, they are charged directly into cars.

The productive capacity of the plant will reach 400 tons per day when the necessary steam generators have been installed. At the present time it does not exceed 200 tons per day.

The steam, which leaves the retorts at a temperature of 150° to 250°, is heavily charged with tar and oil. It passes into a first condenser called "primary" in which it gives up the greater part of the pitch and of the heavy tar which is contains.

The primary condenser is a column with bubbling plates which makes it possible to obtain a partial fractionation. A special arrangement permits the withdrawal of the product at each stage. The regulation is done by injecting cold water onto a definite plate and by changing the points of extraction.

The injection of water is regulated so that the steam leaves the primary condenser at a temperature slightly above 100°.

It then passes into a "secondary condenser" which is nothing else than a surface condenser and from which there are discharged:

1. Medium and light tar.

2. Water charged with complex products, in particular substances of phenolic character, and a very small amount of tar. This water is cooled and separated in large basins and the phenols are recovered.

3. Gas which is delivered into a gas holder. It is composed principally of methane and hydrogen, and possesses a very high calorific power. Mixed with gas from the gas producer, it feeds the steam superheaters.

Conclusion

The plants of the Compagnie des Mines Vicoigne, Noeux, et Drocourt, although they have not yet reached the maximum production which may be expected, have nevertheless reached the phase of commercial operation and are producing at the present time 150 tons of Anthracine per day.

From the technical and the economic points of view, the results obtained are sufficiently encouraging to determine the company to double its plants and to undertake the manufacture of smokeless fuels starting with coals of every sort from its concessions.

The field, whose door we have just opened, is however so vast that many years and the collaboration of the best coal technologists of the entire world will be required to explore it completely.

The production and sale of a more and more perfect synthetic fuel, is coming to be the foremost purpose of the Compagnie des Mines Vicoigne, Noeux, et Drocourt.

Evidently it is also necessary to obtain a maximum value from the primary tar, which will acquire greater value, as natural sources have more difficulty in satisfying the universal demand for liquid fuels.

The ideas which the members of the Conference may be able to offer will contribute to a great work in which the Compagnie des Mines Vicoigne, Noeux, et Drocourt is proud to be associated.

THE TURNER RETORT

By Charles Turner

Glasgow

I will endeavor, first—to lay before you in sequence some of the thoughts which induced me to design and later to build my retort at Poynton near Manchester; secondly, to describe to you the plant at Coalburn, Lanarkshire, and to give you briefly an account of the work done by it; and lastly, to indicate to you the lines along which I propose to develop the plant.

Many years ago I became possessed of a large oil shale field and sought ways and means to exploit it commercially. In the course of my investigations I viewed many different types of retorts and coke ovens—the names given to installations erected for the purpose of converting bituminous substances into more highly-priced products. The installations differed in very many ways but all were alike in:

1. Placing the material in closed chambers.
2. Heating the chambers externally.
3. Requiring an appreciable amount of time to effect the change.
4. Producing a large volume of gas.

I suppose that everyone here has held in his fingers and has observed a burning match. At one end there is yellow flame and the wood at that end appears, as it is called, to be red hot, while the wood imparts no sensation of heat to the fingers. As the yellow flame results from the burning of hydrocarbon vapors it must be assumed that these are produced from some substance in the wood by the action of heat. For lack of another name I will call this substance kerogen. It is evident that kerogen in wood is converted into hydrocarbon vapors by the action of heat much more rapidly than wood conducts heat. The same is obviously true of the wax vesta and of bituminous coal burning in a fire grate. I suppose that you all have heard of colliery explosions. Whether or not the originally ignited gas may have been held under pressure in the coal or have been produced from it by local heating it is now conceded that the resulting explosion dislodges coal dust and that the flame converts the kerogen in the dust into hydrocarbon vapors so quickly

that there is a steady supply of explosive atmosphere and flame so long as the roadways provide enough very fine coal dust.

Reflecting on these facts must incline anyone to think that the quickest way to raise the temperature throughout of any bituminous substance is, first of all, to reduce it to a small size and then to immerse it in a hot fluid so that the whole of its surface is subjected to the action of heat. If the heating fluid be hot enough the kerogen will be volatilized.

Heat converts kerogen into hydrocarbon vapors, but what, if any, effect has heat on these vapors? Long ago, an attendant on a still in an oil refinery remarked upon a curious crackling noise produced in the vessel from which most of the oil had been distilled. Investigation showed that on coming in contact with the relatively hot plates of the vessel the hydrocarbon vapors were converted into other hydrocarbon vapors and pitch, and that these second hydrocarbon vapors were only changed into the liquid state at a temperature much below the boiling point of the original oil. Indeed some of the second hydrocarbon vapors are referred to as permanent gases because they cannot be changed into the liquid state at reasonably low temperatures. This "cracking" reaction will occur whenever the hydrocarbon vapor comes in contact with the relatively hot walls of the vessel whether the vapor be produced by distilling oil or by converting kerogen, and it may be assumed to occur when such vapors come in contact with any relatively hot substance. It is reasonable, therefore, to expect the products produced by the heat treatment of bituminous substances to vary considerably as the heat treatment is varied. And such is the fact.

As my object was to produce oil, it seemed to me to be desirable to heat the material sufficiently only to volatilize the kerogen and then to cool the hydrocarbon vapors produced. But heat can only be transferred from a relatively hot to a relatively cold body and the rate at which it is transferred varies inversely with the difference in temperatures—the greater the difference in temperatures the shorter the time required to transfer a given quantity of heat. The heating fluid must therefore have a temperature higher than that at which the kerogen is volatilized under normal conditions. Can these conditions be changed so as to retard the volatilization of the kerogen?

Consider the case of water. The temperature at which water boils varies as the pressure on the surface of the water varies, rising as the pressure increases. Under normal atmospheric pressure at sea level

water boils at 212°F. If the pressure be gradually increased the temperature of the boiling water rises steadily until it reaches 300°F. under a pressure of 53 pounds per square inch above atmospheric pressure. If the pressure be gradually reduced the temperature of the boiling water drops steadily until it reaches 100°F. under a vacuum of 28 inches of mercury. It is well known that the temperature of water cannot be raised above its boiling point under any particular conditions of pressure, and also that water at boiling point will boil violently and drop in temperature instantaneously when the pressure is reduced.

These well-known facts suggest that the temperature at which kerogen volatilizes will depend on the pressure of the surrounding atmosphere. Experiments confirm this opinion. It is therefore possible to raise the temperature of kerogen above that at which normally it volatilizes by simply increasing the pressure of the surrounding atmosphere. And kerogen at this temperature will be converted instantly into the volatile state by a decrease in the pressure.

It now only remains to choose the most suitable heating fluids which can be varied in temperature easily and instantly. Molten lead does not comply with these conditions but gases do. All gases rise in temperature when compressed and drop in temperature when allowed to expand. It would seem, therefore, that any inert gas heated to a sufficiently high temperature might be chosen. But gases have large volume for little mass and hold vapors by vapor tension so tenaciously as to make it troublesome and costly to extract them from the gas. Superheated steam minimizes these drawbacks whilst possessing the advantages of the gases. I will deal later with the apparent loss arising out of the latent heat of steam.

Speaking generally, all solids, liquids and gases are raised in temperature when heat is added to them. Only when some chemical or physical change is taking place is there a transference of heat without alteration of temperature. So far as I know, the specific heat of different bituminous substances varies between 0.23 and 0.35. The specific heat of Scotch coals may be taken as being 0.25. The specific heat of producer gas, at constant pressure, is 0.28, or approximately the same as that of coal. The mean specific heat of steam, at constant pressure, is 0.5. In other words, a unit of heat will raise the temperature by 1 degree of:

1 unit mass of water, or of
2 unit masses of steam, or of
4 unit masses of producer gas, or of
4 unit masses of coal.

It follows, therefore, that any given weight of superheated steam dropping in temperature through $X°$ will provide enough heat to raise the temperature of twice its weight of coal through $X°$, whereas the same weight of producer gas dropping in temperature through $X°$ will provide only enough heat to raise the temperature of its own weight of coal through $X°$.

A particle of coal immersed in steam at rest will attain the temperature of the steam. No matter how much longer they be left together no further transference of heat will take place between them. But if the steam be moved into a space containing another particle of coal and this be at a lower temperature the steam will drop further in temperature whilst the coal particle is raised in temperature. It is evident, therefore, that the whole of the superheat of the steam is available for raising the temperature of the coal by simply arranging that the hottest steam comes first in contact with the hottest coal and passes through it to the ever cooler coal. Such a procedure will result in a portion of the mass of broken coal attaining the temperature at which the kerogen is volatilized while the remaining portion is still at a lower temperature. To leave the former in the retort until the latter will have attained the same temperature would be equivalent to using the retort for only a fraction of the available time and the alternate heating and cooling would deteriorate the retort very rapidly. Therefore, so far as may be reasonably practicable, every part of the retort should be maintained at a constant temperature throughout its working life. This desirable condition is approached by arranging for the coal as it rises in temperature to move uniformly through the retort. If the retort be vertical and filled with coal, the removal uniformly of a layer from the bottom will permit of a uniform sinking by gravity of the coal in the retort. Gravity operates without mechanical contrivances and does not go out of operation. To conform to this condition of the hottest coal being at the bottom of the retort, the superheated steam must enter the retort at the bottom and leave it at or near the top. As the retort should always be full, it must be filled at the top uniformly. If a bottomless hopper containing coal be placed above

it then as the coal sinks in the retort it will be replaced by coal sinking from the hopper.

Now consider the steam. It must enter at the bottom of the retort and it must alternate in pressure within the retort and be in contact with the coal. To be in contact with the coal implies that the steam and coal are at rest, and in order to be at rest the steam must be kept in the retort. In order to hold it in the retort, the entrances to and exits from the retort must be closed by some means, say by valves. If the inflow of steam to the retort be not interrupted, pressure will be built up in the retort whilst all the valves are closed. The opening of a steam outlet valve of ample size at the top of the retort will cause an immediate drop in pressure throughout the retort.

Such were some of my thoughts! What do they amount to? Before considering the reactions which may be expected to take place in such a visualized retort it is desirable to apprehend clearly the following postulates:

a. Heat is transferred from a relatively hot to a relatively cold body by contact or radiation or convection and from a hotter part of a body to a cooler part of the same body by conductivity.

b. All carbonaceous materials are bad conductors of heat.

c. Hydrocarbon vapors are produced and released by subjecting most carbonaceous materials to the action of heat.

d. The hydrocarbon vapors are produced and released at different temperatures.

e. The temperature at which the hydrocarbon vapors are produced and released rises as the pressure increases.

f. Conversely, the hydrocarbon vapors on the point of formation in carbonaceous material being heated under pressure escape freely when the pressure is reduced.

g. Hydrocarbon vapors are changed into other varieties of hydrocarbons when subjected to the action of heat. This reaction is called "cracking."

h. Many hydrocarbon vapors are changed into liquids by the action of cold.

i. An increase in pressure raises the temperature and reduces the volume of hydrocarbon vapors.

j. A decrease in pressure lowers the temperature and increases the volume of hydrocarbon vapors.

k. Heat causes the vapors to increase in volume, the pressure remaining constant.

l. Cold causes the vapors to decrease in volume, the pressure remaining constant.

The plant consists of:

A superheater capable of delivering an adequate amount of low pressure steam at a particular high temperature to the bottom of

A vertical metal retort provided with mechanical means for continuously charging it at the top and discharging it at the bottom and fitted, at or near the top with

A gas outlet valve so arranged that it will open at a particular pressure and remain open until the pressure has dropped to a particular lower pressure, when it will close. And

A tubular condenser to receive and to condense the vapors passing through the valve from the retort.

The reactions which take place in the retort, working normally, starting from the instant when the valve closes, are as follows:

Each particle of carbonaceous material at the bottom of the retort is enveloped in and heated by the incoming superheated steam (*a*) and if sufficient time be allowed its temperature will become the same as that of the steam. As there is no outlet for the steam at the bottom of the retort, it is pressed by the ever-incoming steam upwards and into all the crevices between the particles of material, transferring heat in its upward course to the ever-descending material in the retort. In this manner the material is heated gradually under continuously increasing pressure to a temperature which varies throughout the retort, being lowest at the top and highest at the bottom. The increase of pressure raises the temperature (*i*), and at the same time tends to retard the emission of the vapors (*e*), and forces the steam into the crevices of the material where it loses heat and is reduced in volume (*l*) whilst raising the temperature of the material (*a*). When the pressure has reached the desired maximum the valve opens, the pressure throughout the retort is at once reduced by the escape of the steam and vapors to the condenser and simultaneously an immediate drop in atmospheric temperature takes place (*j*) at every point in the retort.

The reduction of pressure allows of the formation and release of the volatiles from all the material possessed of the temperature necessary to bring about destructive distillation (*c*, *d*, and *f*) and also cools them (*j*). The volatiles produced at a low temperature are given off at that

temperature before the material is heated to the higher temperature at which other volatiles are produced. At the instant of formation the hydrocarbon vapors are gaseous and are cooled (*a*) by escaping into an atmosphere of steam at a lower temperature. The gaseous hydrocarbons are intimately mixed with and carried upwards through the ever-cooler material by the steam, and must at some point be condensed into liquid hydrocarbons, because the outgoing steam has a temperature lower than that at which the hydrocarbons can exist in the gaseous state (*h*). In their conversion from the gaseous to the liquid state the sensible and latent heat possessed by the hydrocarbons is transferred to the steam (*a*) which in turn transfers it to the carbonaceous material (*a*). As the hydrocarbons never come in contact with anything hotter than themselves, they are not subjected to any risk of cracking (*g*). As condensation of the gaseous hydrocarbons takes place throughout the mass of the steam it is obvious that a hydrocarbon or oil mist is produced each globule of which is enveloped in and carried by steam into the condenser. In the upper part of the condenser the sensible heat of the steam is transmitted by the tubes to the condensing water. Simultaneously the steam is heated by the globules of oil. As the condenser is of ample size the steam enveloping the globules of oil is changed to films of water each containing a globule of oil all floating in an atmosphere of water vapor. Further condensation changes the whole of the vapors from the retort into a mixture of oil and water and as such they pass from the condenser to the separator. In this way the condenser, acting as an exhauster whilst the valve connecting it to the retort is open, expedites the escape of the vapors from and the reduction in pressure in, the retort and the closing of the valve.

The cycle of reactions is repeated continually.

Reflection will make evident that:

1. The steam performs several functions, viz.:
   - *a*. Heats the material to and maintains it at the temperature at which destructive distillation takes place.
   - *b* Receives and protects the gaseous hydrocarbons.
   - *c*. Transmits the sensible and latent heat of the hydrocarbons to the material.
   - *d*. Envelops and carries the hydrocarbons in globular form through the material in the retort and into the condenser.
   - *e*. Transfers its sensible and latent heat through the tubes in the condenser to the condensing water.

f. Becomes a film of water—the most effective of all cooling mediums—enclosing each globule of oil.

2. The alternating pressure controls the formation, release and movement of the hydrocarbons, and results in the recovery of the maximum yield in the liquid state.

3. The heat required to convert the material in this retort, provided the plant be efficiently lagged, must be less than in any other retort, because the whole of the superheat of the steam and the latent heat of the hydrocarbons are used to heat the material. As "craeking" does not occur it is not necessary to provide the heat to effect this reaction. The latent heat of the steam is used to heat the boiler-feed water; or to convert into low pressure steam the practically boiling water after it has been used as cooling water in the condensers.

4. The difficulty of eondensing the hydrocarbons is reduced to a minimum.

5. The throughput capacity of this retort must be greater than that of any externally-heated retort of the same cubic size, because the material is heated by immersion in the heating medium, and not by the very much slower method of transmitting heat by radiation from and conductivity through the walls of the retort and through masses of the material (*b*).

Having tried and failed to destroy the foregoing argument I set to work to design this visualized retort and again attacked the problem by the method known as question and answer.

How can the material be made to sink uniformly in the retort? An archimedean screw on a vertical shaft, provided with suitable means to rotate it at any desired speed, seems to provide a means. The horizontal section of the chamber in which the archimedean screw rotates must therefore be circular. The shaft itself is a permanent support for a vertical core of material in the center of the retort. The retort must therefore have a sectional area at its base greater than that at the top to allow for the space occupied by the shaft. The retort may therefore be a vertical truncated cone with the larger end at the base. A throat inside the retort at the top will isolate the material from the steam and vapors entering the outlet to the condenser.

It is now necessary to design a valve which will pass solid material when open and be steam tight when elosed and be capable of working at very high temperatures. So far as possible wear must be reduced

to a minimum and troubles due to expansion must be eliminated altogether. The valve must obviously be either a sphere resting in a cone or two truly flat surfaces. I chose the former. The seat of the valve, being in a horizontal plane and above the sphere, will not be touched by the material dropping through it. If the sphere drops freely by gravity the material will not rub on it. Mount a segment of a sphere by means of a ball joint on to a vertical shaft the center line of which contains the centre of the valve seat, rigidly attach this vertical shaft by means of a horizontal arm to a horizontal shaft at right angles to it the ends of which are supported in and pass through bearings and there is the nucleus of the valve. Fit epicyclic gearing on the horizontal shaft, arm and under side of valve and the valve will turn on its axis as it swings, leaving its seat with a twisting movement and re-seating itself with a twisting movement. Any particles of dust will thus be removed by a grinding action. Provide a second rotatable shaft with a toothed wheel engaging with the epicyclic gear so as to rotate the valve whilst it is stationary and there's the valve. A lever fixed on the horizontal shaft provides a simple means of swinging the valve. The valve can be held closed by applying a suitable force to the lever. This force may be provided by a wedge, or a weight, or a steam cylinder, or a hydraulic cylinder, or a solenoid. The last three contrivances are cumbersome and costly to install and, although they can be adapted to operate the valve, their application would be a great extravagance because they provide great power to swing the valve which can be swung by hand. The weight also cannot be adopted because it introduces difficulties in the opening of the valve. Obviously the wedge is the best method of holding the valve closed. It is desirable that the valve should, when released, drop instantly from below its seat so as to obviate any risk of the material rubbing on it. The withdrawal of a wedge, so releasing the lever, would allow the valve to drop instantly. Can a wedge be fashioned to close the valve? A cam is a special form of wedge. A large cam, of special form, rotating in the plane which contains the swinging lever, and engaging with the lever can be rotated without the expenditure of much power and will close the valve and will hold it closed against pressure and, when it releases the lever, will allow the valve to drop open by gravity.

In order not to interrupt the steady working of the retort a pair of such valves, with a hopper between them, must be supplied above the retort and another pair below the retort. When one valve of a pair

is open the other must be shut. In this manner the retort is kept closed.

Now, consider the alternating pressure valve. Arrange the valve so that the pressure in the retort is above it and tends to open it. On the end of the vertical spindle fit a piston working in a steam cylinder above the valve. Steam below the piston will hold the valve closed. Attach mechanism to cut off and exhaust the steam when the pressure in the retort has reached the desired maximum and to close the exhaust and to admit the steam when the pressure has dropped to the desired minimum and there is the alternating pressure valve. I have adopted a solenoid to operate the steam valves. The solenoid is operated by pressure mechanism connected to the retort below the archimedean screw.

Coal mining experience has shown that gas sometimes bursts from coal. As rapid emission of gas from coal may occur in the retort, it is desirable to provide a relief valve to cope with it. By means of a reducing valve supply the steam at a particular pressure to operate the alternating pressure valve and it is a relief valve as well as an alternating pressure valve.

When being heated the retort will expand. The difficulties due to expansion will be overcome by supporting it and its hoppers at the level of the archimedean screw. The retort must be completely covered by a really good heat-insulating material. That completes the retort. To complete the plant it is necessary to supply a furnace, a superheater, a boiler, a feed-water heater, a condenser and a separator with the necessary connections.

If you have understood my story you are now aware that my plant for the production of oil from bituminous materials consists of a number of vessels in which heat is transferred as efficiently as possible from one substance to another. In order to demonstrate the soundness of my argument to anybody sufficiently interested to visit it I built a brick retort house at Poynton near Manchester which stands 35 feet to the eaves, to hold a small retort capable of treating any bituminous material under such conditions as would obtain working commercially. (Fig. 1.) The valves *e*, *f*, *g* and *h* are identical with those for a commercial plant. To procure data, I fitted my superheater and retort with pyrometers.

THE PLANT IN OPERATION

The retort and its hoppers, valves and extracting gear are constructed entirely of iron and steel.

The retort a is a truncated cone set vertically with the larger end at the bottom. An archimedean screw mounted on a vertical shaft b acts as a false bottom to the retort and when rotated slowly and continuously takes a slice from the base of the spent material in the retort and drops it into the hopper c where it rests on the valve g. When the valve g is opened the spent material drops into the hopper below and rests on the valve h. The valve g is now closed and valve

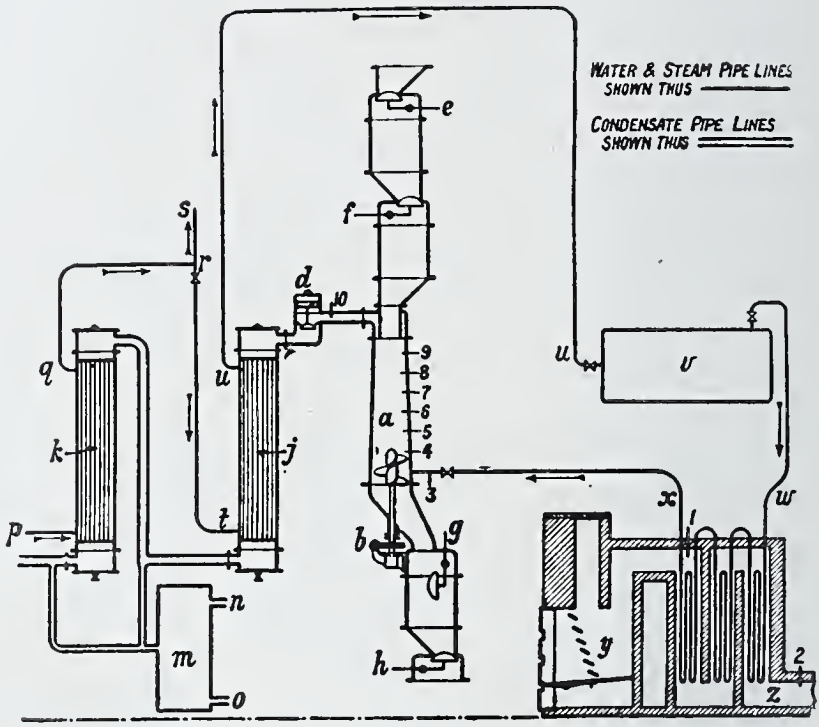

FIG. 1. DIAGRAMMATIC ARRANGEMENT OF THE PLANT

opened so allowing raw material to drop into the hopper forming the extension of the upper end of the retort where it rests on the material in the retort supported by the archimedean screw. Valve f is now closed and valve e opened to allow a fresh charge of raw material to enter the warm hopper and to rest on valve f. Valve e is now closed and valve h opened, so allowing the spent material to drop out which has been resting on it and cooling while in the hopper. This cycle of valve operations is repeated continuously. In order to prevent air from entering the hopper above valve h, wet steam is introduced into it, just under valve g, simultaneously with the

release of valve *h* the amount being regulated so that steam just blows through valve *h*.

Superheated steam is taken by pipe *x* into the retort. It cannot get out at the bottom because of valve *g*, nor out at the top because of valve *f*, nor out through valve *d* while this is closed. Consequently, it builds up pressure in the retort whilst being held in contact with and transferring heat to the material until the pressure-operated mechanism opens valve *d*. When valve *d* opens the steam and hydrocarbon vapors, produced and released by the drop in pressure, are carried by the steam to the feed-water heater *j*, and the pressure drops until the pressure-operated mechanism closes valve *d*. No attempt is made to interrupt the flow of superheated steam into the retort.

Feed-water heater *j* changes the steam into water. The liquid portion of the condensate from *j* flows down and into the separator *m*, whilst the gaseous portion rises into the condenser *k* where it is cooled to the utmost. The liquid portion of the condensate from *k* flows down and into the separator *m*, while the gaseous portion, if there be any, passes to a scrubber. The oil and water separate in *m* and flow off respectively by pipes *n* and *o*.

Circulating water enters the condenser *k* at *p* and leaves it at *q*. At *r* it is divided, one part, equivalent to the amount of steam taken from the boiler, passing into feed-water heater *j* at *t*, the remainder flowing away at *s*. As *j* aims only at changing the steam from the retort into water it is obvious that the circulating water leaving *j* at *u* may be practically at boiling point. Thence it is taken to the boiler *v* and converted into steam which travels through the superheater pipe *wx* into the retort. The superheater is heated by gas made by the furnace *y*.

In the Poynton retort I treated 32 different materials comprising peats, lignites, oil shales, cannel coals and bituminous coals. Only the last class provided any difficulties. Some of them swelled so much that three months after starting work I ordered a new retort body to be made with the biggest taper possible of being fitted between the hoppers above and below it. At the same time, I put in a new and flatter archimedean screw because the residue from an Asiatic lignite would not rest on the old one. No difficulties were experienced with the new screw but, whilst a great improvement on the original, the new retort did not obviate all the difficulties of treating, satisfactorily, such coals as become very plastic when

heated, or, as my workmen called them, "the coals which melt." These prevent the steam from penetrating the mass quickly and so take very much longer to treat. The worst examples of such coals required to be treated for 12 hours in the retort while the best of the non-melting coals required only 2 hours, the particles of raw coal being of similar size in each case.

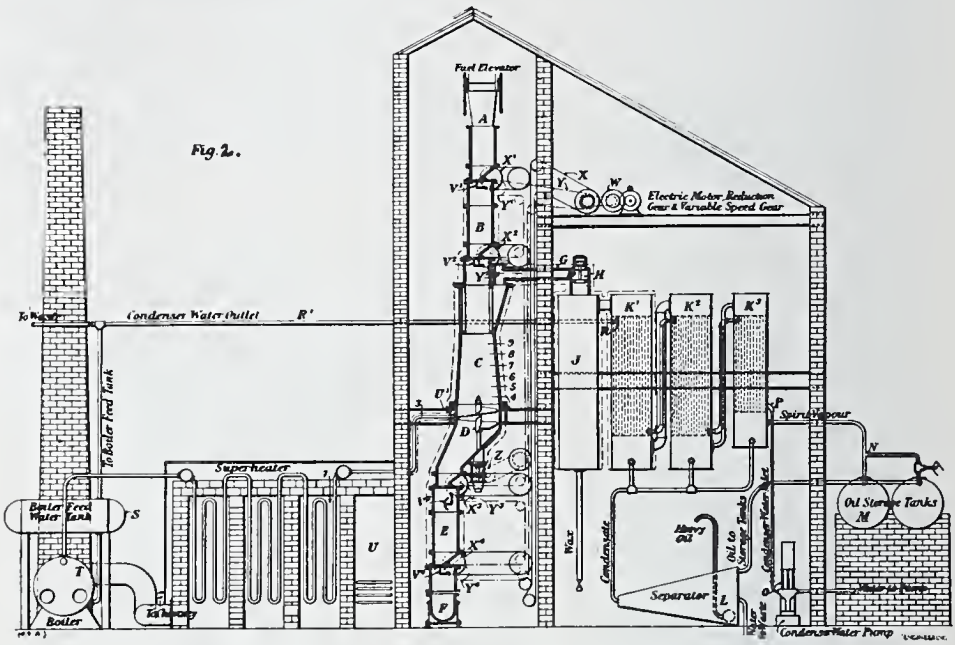

FIG. 2. SECTIONAL ELEVATION OF COMAC PLANT

A, receiving hopper; *B*, air lock and preheating chamber; *C*, retorting chamber; *D*, archimedean extractor screw; *E*, air lock and cooling chamber; *F*, movable discharge hopper; *G*, outlet for steam and volatiles; *H*, automatic pressure-operated valve for controlling internal pressure of retort; *J*, wax extractor; *K1*, *K2*, *K3*, water-cooled condensers; *L*, oil and water separator; *R* and *R1*, condenser water outlet and return to boiler feed tank; *U*, producer fired superheater; *V1*, *V2*, *V3*, *V4*, retort valves for controlling passage of solid materials; *X*, endless chain for operating valve gear at *X1*, *X2*, *X3*, and *X4*; *Y*, endless chain (shown in broken line) for actuating valve grinding gear at each valve position; *Z*, chain drive to archimedean screw extractor.

So far as I am aware, the best working conditions can be determined only by trial. For instance, treated with steam at 400°C., one oil shale left a residue containing less than 1.5 per cent of volatilizable matter, whilst another was changed only into a crude bitumen. With steam at 410°C. the former set up a gas reaction whereas no gas, as distinct from oil vapors, was produced from the latter with steam up to 600°C.

The yields of oil in gallons per ton of material treated at Poynton varied for peats up to 20, for lignites up to 60, for oil shales up to 80, for cannels up to 35 and for bituminous coals up to 45.

The peculiar temperatures recorded when treating some of the above materials inclines me to suggest that the conversion of kerogen into the volatile state is not always accompanied by the absorption of heat and that indeed in some cases under the conditions prevailing, it is actually accompanied by the production of heat. This thought suggests that the physical conditions prevailing may influence the reaction just as a forced draught promotes the combustion of anthracite and the expansion and contraction of the lungs converts oxygen into carbon dioxide.

Examination and observation of the Poynton plant at work induced Mr. McMillan to erect the Comac plant at Coalburn. Figure 2 is a diagrammatic view of this plant. Whereas the Poynton retort was 20 inches in diameter at the base this Comac retort is 4 feet in diameter at the base. The valves on the Poynton plant were operated by hand. The valves on the Comac plant, identically the same size, are operated by endless chains.

Whenever the 2 cwt. charge of coal is put into the top hopper of the Comac plant it carries air with it. When the charge enters the retort air passes in with it. This air must be allowed to escape through the condensers. When the air vent was open to the atmosphere the condensation of the steam and oil vapors in the condensers created a vacuum and air was sucked in. The steam and oil vapors coming from the retort when the alternating pressure valve opened displaced the air in the condensers. The air carried away with it some oil spirit by vapor tension. It was not practicable to fit a non-return valve on to the air-vent because of the disturbance caused thereby in the separator. So the air-vent was connected to the oil-storage tanks and the non-return valve placed in a branch in that pipe line. The vacuum now created in the condensers by the closing of the alternating pressure valve sucks spirit from the oil in the storage tanks. Some of this spirit is absorbed by the oil vapors and produces a separation of the crude oil into two portions one being heavier than water and the other lighter than water. In addition to effecting a separation of the oil there is an increased yield of 3 gallons per ton from the coal.

The alternating pressure valve has operated as slowly as twice a minute and as quickly as 12 times a minute. The best time period

for any particular material can be determined only by trial. Generally speaking the pressure is built up to 5 pounds per square inch in 8 seconds and drops to 2 pounds per square inch at the bottom of the retort within 1 second after the opening of the alternating pressure valve. Generally, when treating bituminous coals one ton of steam

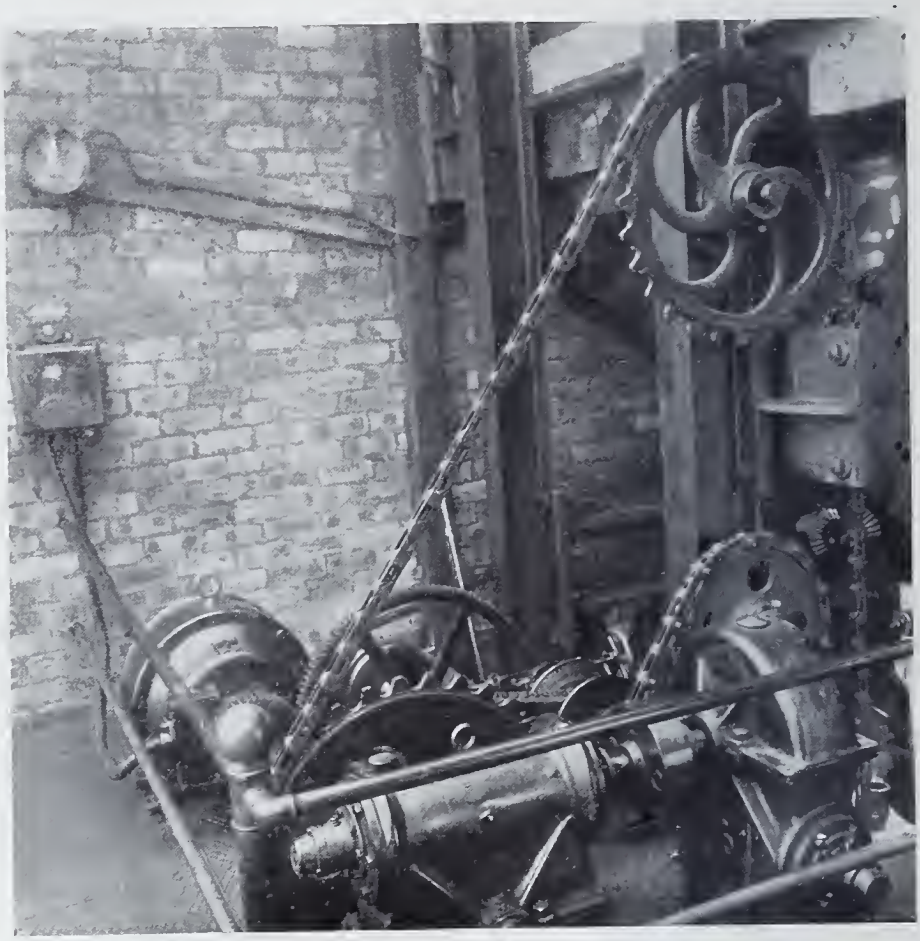

FIG. 3

at 650°C. is required to treat 1 ton of coal. The superheating of this steam has required less than $1\frac{1}{2}$ cwt. of fuel.

Figure 3 shows the little motor, which is never called upon to develop 1 horsepower, the reduction gearing including a variable speed drive, the hollow stud chain which opens and closes the valves in turn by means of the group of pegs in it, seen on the lower of the

FIG. 4

two chain wheels fixed on the stanchion. The upper and larger wheel rotates counter-clockwise carrying the loaded chain. Figure 4 shows the pegs in the chain more clearly.

Figure 5 shows parts of the aforementioned chain wheels affixed on the stanchion and also a slotted disc. The chain passes between this disc and an identical disc behind it. The pegs in the chain engage in these slots and rotate the discs which in turn rotate a chain

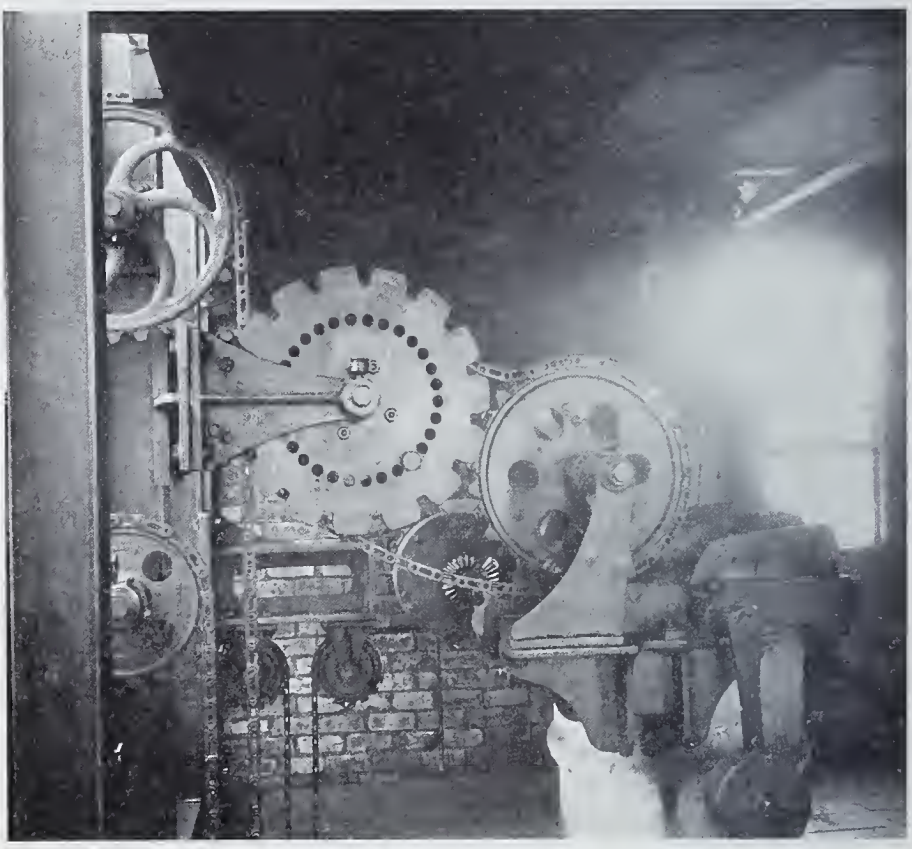

FIG. 5

wheel on the same shaft by means of the driving pin. The chain wheel, mounted on the shaft carrying the discs, drives another chain wheel by means of the chain, causing the cam on the shaft, to which it is keyed, to rotate clockwise, so releasing the lever which holds the valve closed. At the back is seen a smaller endless chain which rotates the valve when it leaves its seat until it is reseated.

When the pegs pass away from the slotted disc this falls by

gravity counter-clockwise on to a pawl, and slackens the driving chain. Figure 6 shows the lever released, the driving chain tight

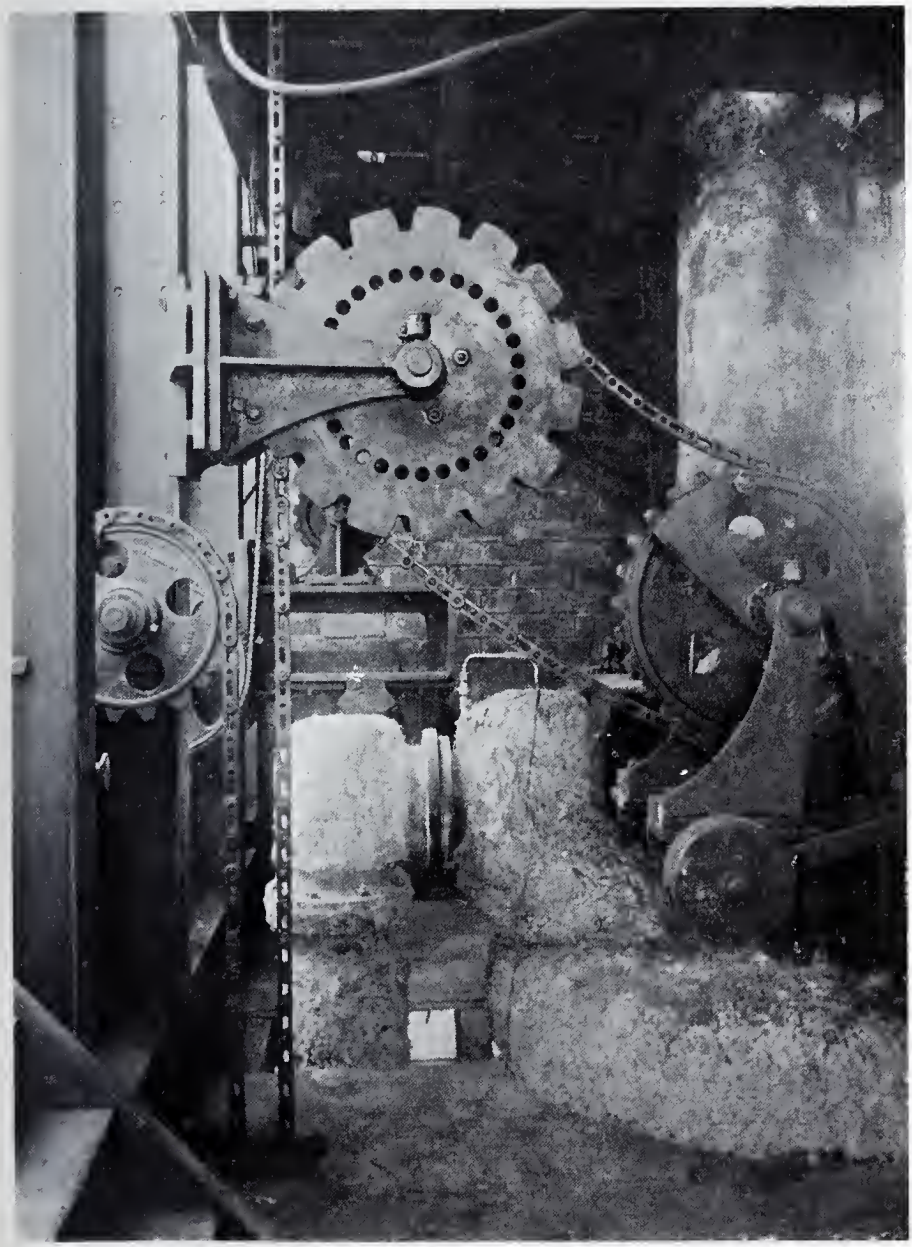

FIG. 6

and the cam half way round to reengage the lever. Figure 7 shows the rollers on the toe of the cam pressing the plates down and the

lever up into the horizontal position, and raising the valve up to its seat. Figure 8 shows the cam mechanism diagrammatically. The

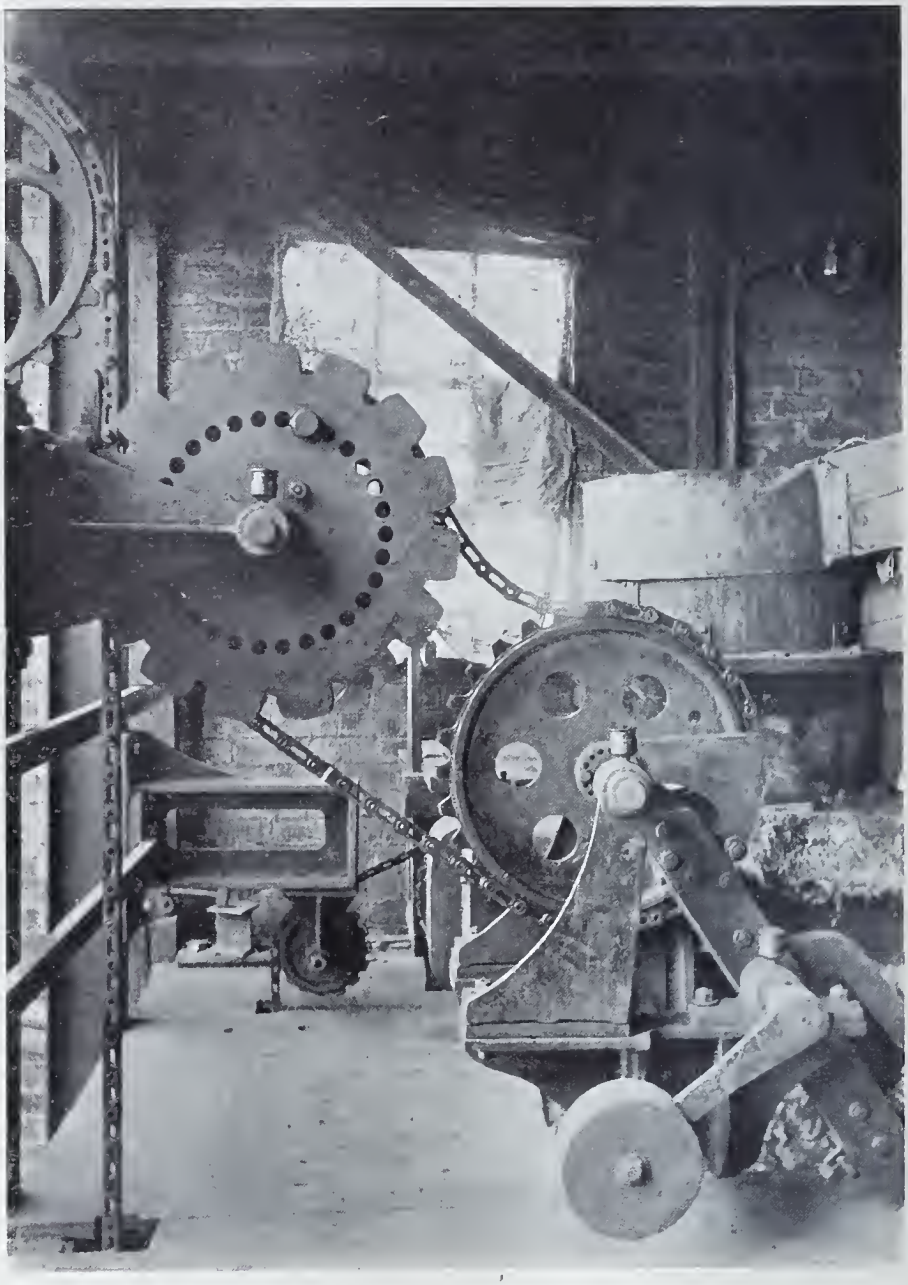

FIG. 7

lever A is keyed on to the shaft carrying the valve and is attached to a pair of plates B, which are loose on the shaft, by the bolt passing

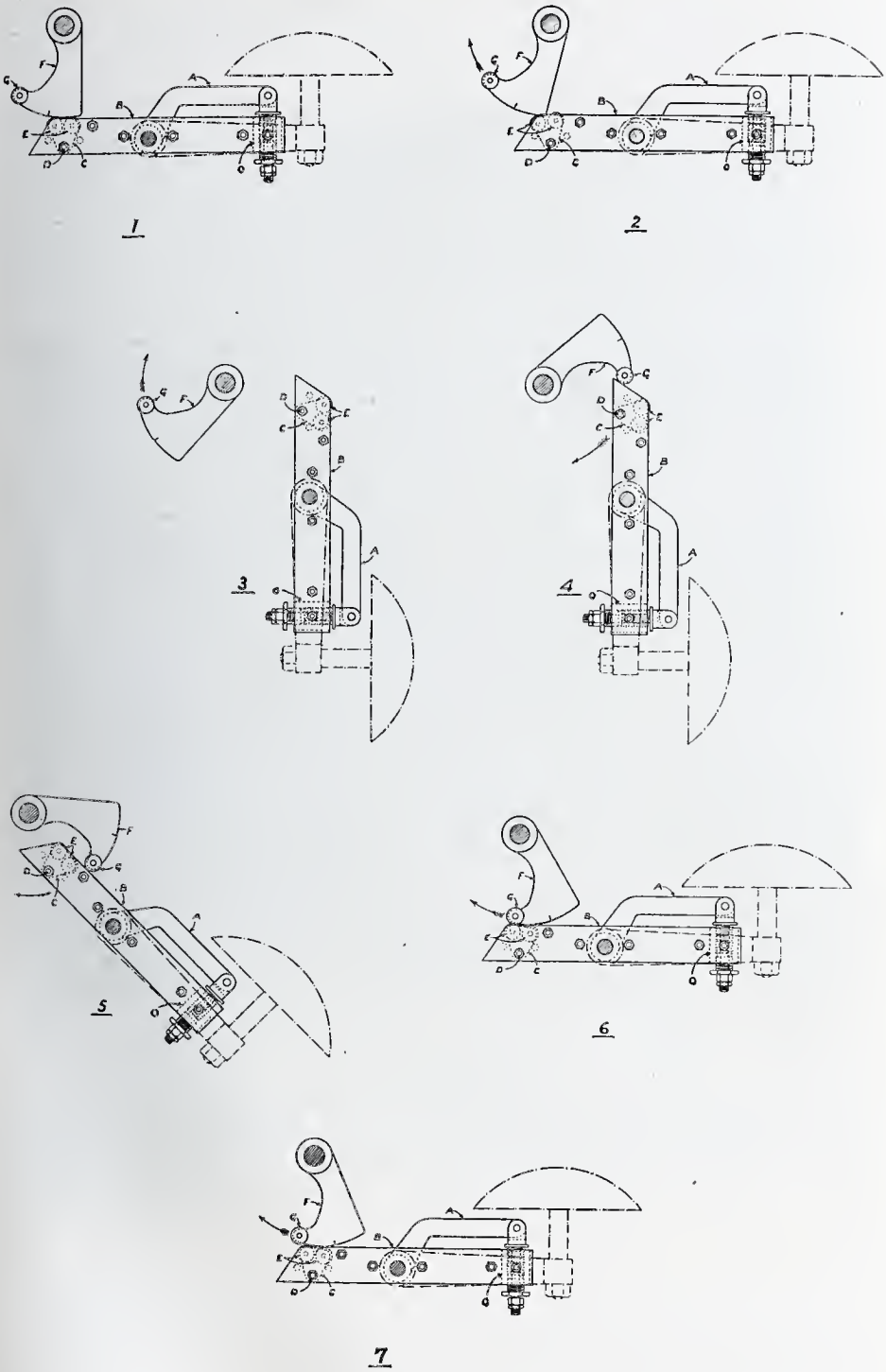

FIG. 8

through the swivel block O. The bolt passes through a spring which can be compressed by a screw-up gland in the swivel block. At the other end of the plates B is a fulcrum D carrying two triangular plates C supporting spindles on which 2 rollers E are placed between the plates. Stop pins will prevent the triangular plates from tilting too far in either direction. A cam F is keyed on a shaft parallel to that on which the lever A is fixed. The cam F is shown at rest in No. 1 position. The cam is made to rotate clockwise. When the heel of the cam runs off the roller E, No. 2, the plates C carrying the

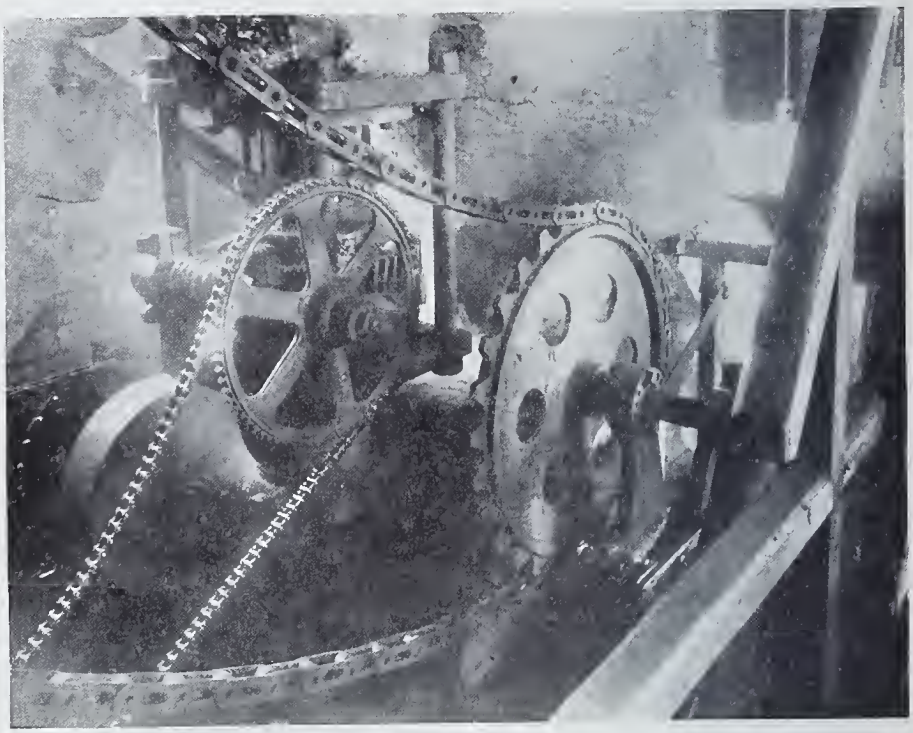

FIG. 9

rollers E tilt on to the stop pin and so allow their fulcrum D to rise which permits the spring to expand. This releases the pressure on the valve. No. 3 shows the cam clear off the rollers E and the valve open. It will be observed that the triangular plates C have now tilted on to the other stop pin. No. 4 shows the rollers G on the toe of the cam engaging with the plates B. As the rollers G traverse a particular orbit, Nos. 5 and 6, they push the plates B down and raise the valve up to its seat. No. 6 shows the cam about to engage with the rollers E just as the rollers G are leaving the plates B. No. 7

shows the cam exerting pressure. Note the compression of the spring in Nos. 7 and 1.

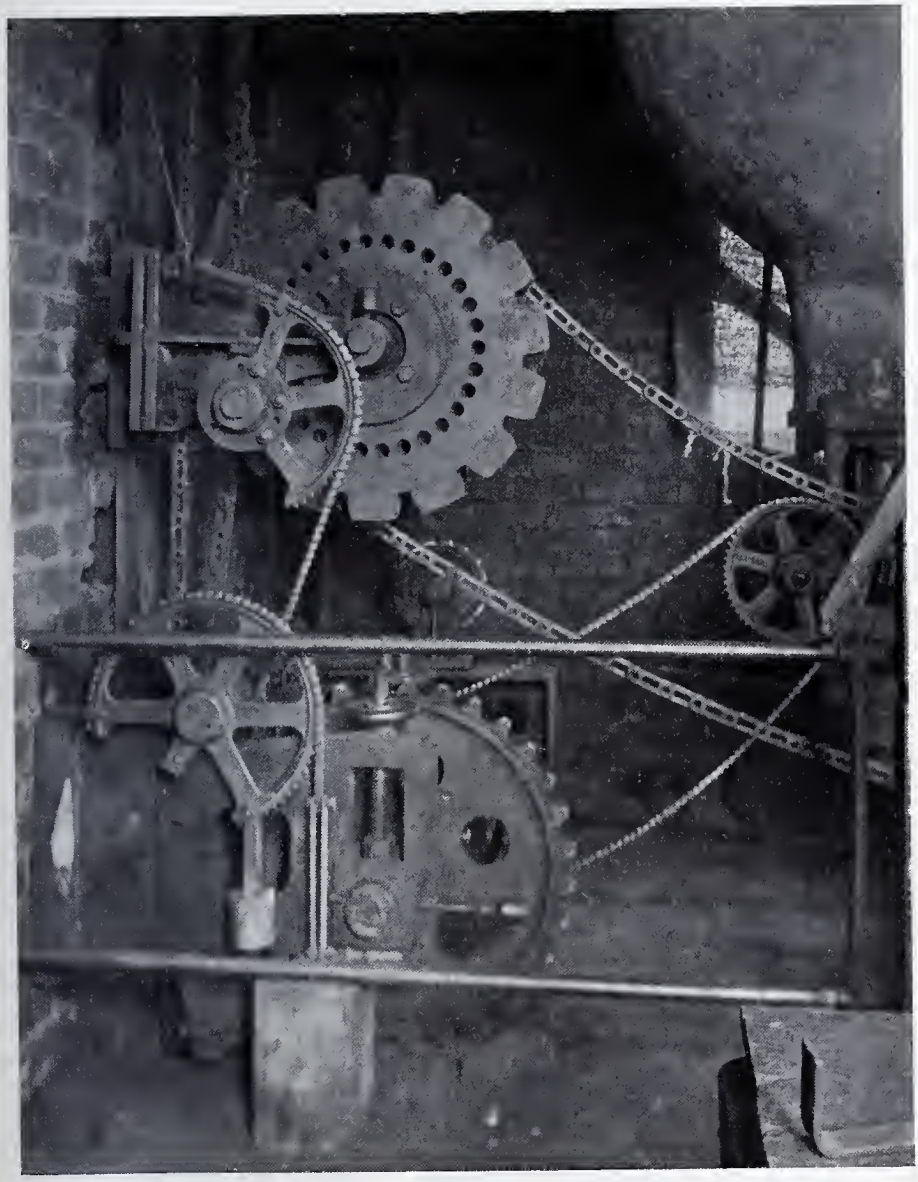

FIG. 10

Figure 9 shows the footstep and gearing of the archimedean screw. It is just possible to see the helical wheel, mounted on the archimedean screw shaft, which engages with a worm having a chain wheel

A mounted on the end of its shaft. The chain wheel *A*, (Fig. 10), is driven by a chain which in turn is driven by a chain wheel *B* not visible on this photograph. Chain wheel *B* is mounted on a shaft on

FIG. 11

which is fixed a chain wheel engaging with the main driving chain. The shaft carrying these two chain wheels is supported in two guide blocks free to rise vertically. In the event of the pull on the chain

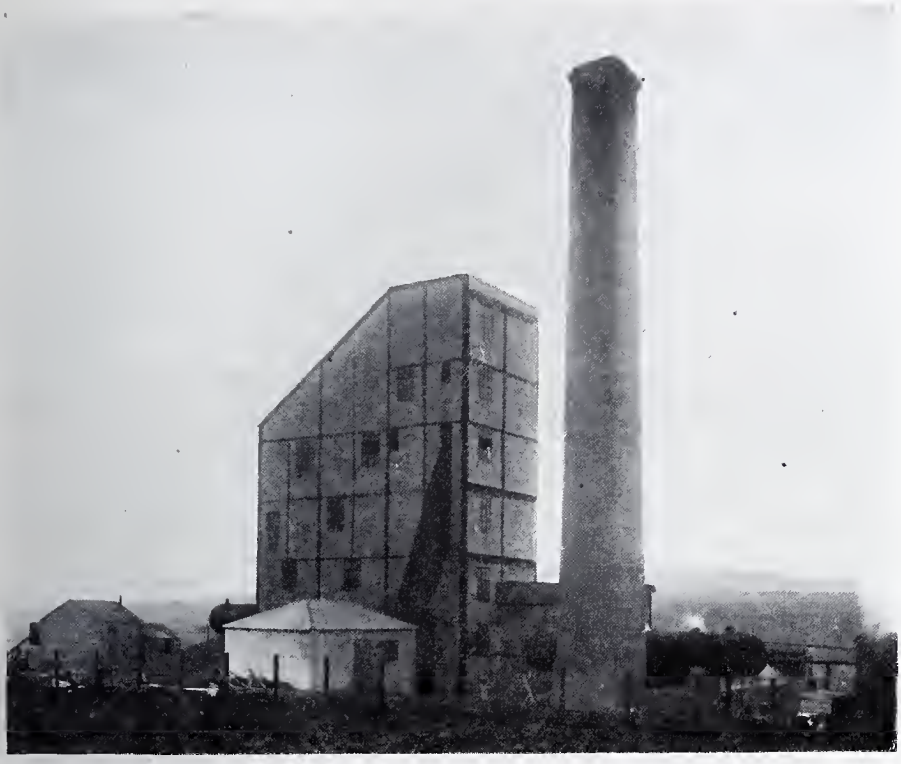

FIG. 12

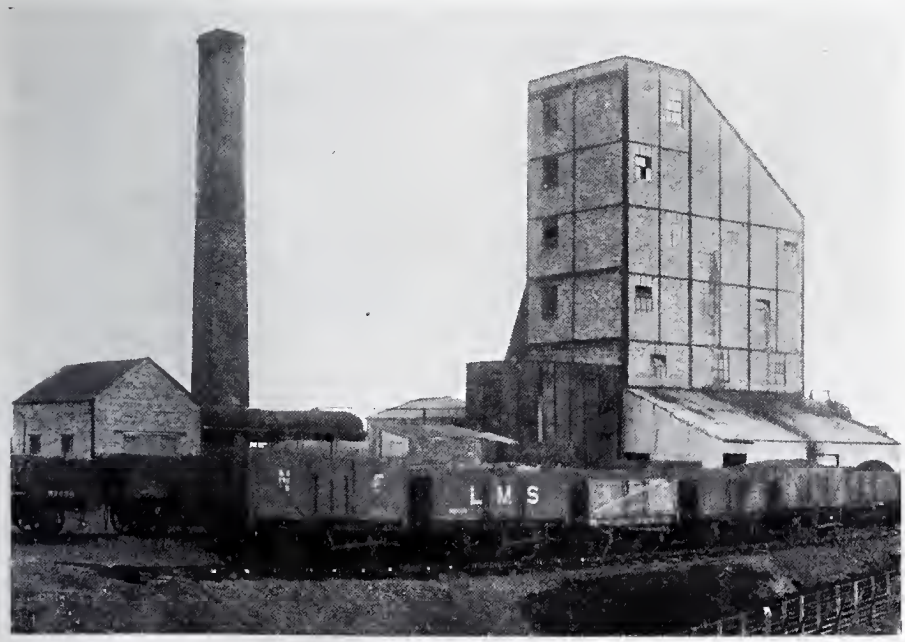

FIG. 13

driving the worm becoming excessive by reason of the hopper below the screw being choked or by any other cause, the shaft will rise and will by means of a Bowden wire operate the motor switch and stop the motor. There is mechanism also to disengage the driving chain from the chain wheel whilst the valve immediately below the archimedean screw hopper is closing. By this means the archimedean screw is brought to rest, so eliminating the risk of material dropping off the screw and being nipped between the valve and its seat while the valve is closing.

Figure 11 shows the hopper truck into which the residue is discharged at the bottom of the retort.

Figure 12 shows an outside view of the premises from the back. The elevator is shown.

Figure 13 shows the premises from the front. The superheater is at the near end of the retort house.

Having described the plant I will now tell you of the material treated in it.

The material being treated in this plant is composed of a mixture of double and treble nuts made from coal coming from six seams in the Bankend Colliery.

The mixture is by no manner of means homogeneous nor uniform, and it differs widely from wagon load to wagon load. But speaking generally it contains:

	per cent
Carbon	44
Volatiles	28
Ash	13
Water	15

Per ton of coal treated, it yields some 30 gallons of oil, one-third of which is recovered in the wax-trap, and some 14 cwt. of solid residue with $1\frac{1}{4}$ tons of condensed steam water. This water is made up of (1) the steam required to raise the temperature of the coal to that at which the volatiles are produced and released, (2) the steam required to produce the volatiles, (3) the steam required to evaporate the water in the coal and (4) the water in the coal itself.

There is no emulsion of oil and condensed steam water. Separation takes place readily and quickly. The oil is practically water-free. It has a specific gravity of 0.945 and a flash point of 58°F.

The solid residue is thrown on to cold water contained in a tank.

The portion which floats, consisting of over 10 cwt. is sold. The portion which sinks is the only fuel supplied to the producer attached to the superheater. The surplus goes to the boiler fire hole.

The portion which floats has the following analysis:

	per cent
Fixed carbon	82.24
Volatile	7.45
Sulphur	0.45
Ash	6.23
Water	3.63

This fuel has a calorific value of 13,788 B.t.u.'s and an evaporative power of 14.27 pounds per pound of fuel.

During the summer of 1927 it became evident that the Comac fuel was improved by allowing it to soak in the superheated steam. Leaving it soaking in the retort materially reduced the throughput of the retort. But the strength of the fuel was very much improved. So to increase the throughput capacity of the retort while continuing to make this strong fuel a distance piece 7 feet long (Fig. 14) was put in between the flanges forming the joint between the retort and the bottom hopper. This had of necessity to be cylindrical. A continuation of the conical retort would have been preferable. The change has produced the results expected of it. Although the retort is now 14 feet in depth the solid fuel shows no evidence of having been crushed. The throughput was restored to 10 tons per day of 24 hours.

I have shown the temperatures at the different zones before and after the alteration. As those in the old retort have not changed it may be presumed that all the oil is produced in the old retort and that the friable fuel merely hardens in the extension piece.

It occurred to me about the same time that I might operate the clutches mechanically which are used to engage and to disengage the mechanism rotating the valves from the driving chain and so dispense with the services of two boys, one above the retort and one below the retort. I replaced the sun and planet reduction gear, bevel drive and expanding clutch by a worm reduction gear, and plate clutch. The opening of the valve now engages the clutch and starts the rotation of the valve. The valve continues to rotate until all the dust between the valve and the valve seat has been ground away. The resistance to rotation is then increased and intensifies the end thrust

set up in the worm sufficiently to overcome the spring-controlled catch holding the clutch plates together so de-clutching the rotating mechanism from the driving chain. This device has now been operating for over a year without a hitch of any kind.

Another difficulty arose out of the favor shown to coking coals by

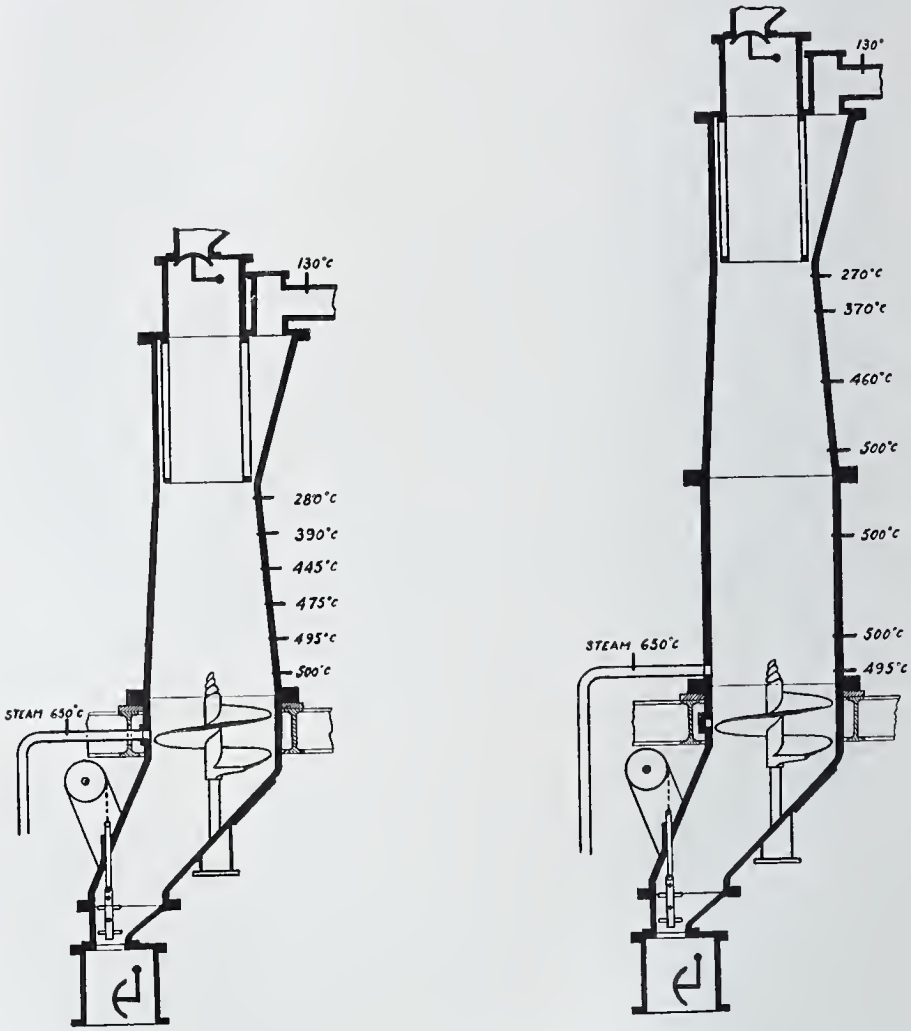

FIG. 14

people sending coals for testing. The archimedean screw is 4 feet diameter and its boss is 11 inches diameter. As the pitch of the screw is 15 inches, it is conceivable that a block of coke may have the vertical section of 15 inches by $18\frac{1}{2}$ inches broad and be of variable length. It is conceivable and indeed it often happened when treating highly

coking coals that such a block would not fall through the valve which is only 12 inches diameter. To get it through the valve it was

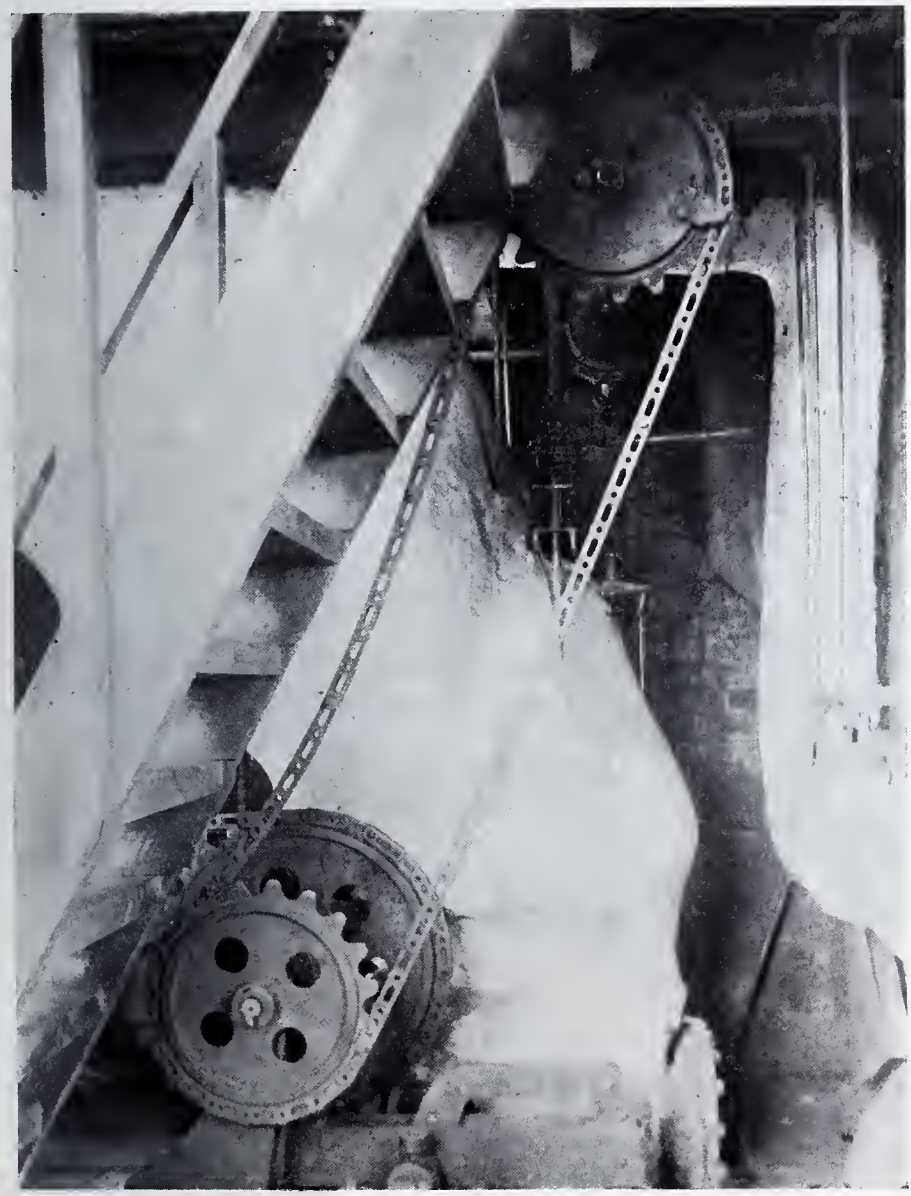

FIG. 15

necessary to by-pass the steam from the retort, to open both bottom valves and to break the block by means of a long poker put up through the valves from the ground floor. This operation took 10 minutes

but it enabled the most highly coking coal in the world, The Lower Mountain Mine of Lancashire, to be treated successfully. To overcome this drawback a pile-driver poker has been put into the archimedean screw hopper. This is raised (Fig. 15) vertically by an endless hollow stud chain driven from the valve cam shaft. Pegs in this chain engage a finger in a disc keyed on to a horizontal shaft on which is mounted a chain wheel carrying a chain attached to the top of the poker spindle. The peg runs off the finger and the pile driver drops on to the block of coal resting in the valve opening. The pile driver is raised and dropped several times while the valve is open. It is stationary when the valve is closed. This mechanism also has worked without a hitch for over a year.

As the motor had little to do I have now coupled to it a fan to provide the primary and secondary air for the gas producer. (Fig. 16). I have also taken out the spur gearing and put in chain gearing. These alterations have reduced the power required until now it amounts to about ½ h. p.

The coal being treated is sold in Glasgow at 14/– per ton. As the railway freight is 5/– per ton, it is evident that only 9/– per ton is received by the colliery company for it. The Comac plant is near to the colliery. If it were on the colliery site it would not cost 1/– per ton to convey the coal from the screens to the foot of the elevator at the retort house. However, assume a charge for transporting it of 1/– per ton. The cost of the coal to the retort is then 10/– per ton. This is converted into smokeless fuel and oil. After providing the fuel needed by the boiler and superheater there is sold:

	s	d
10 cwt. Comac Fuel @ 25/–	12	6
20 gallons oil @ 7½d	12	6
10 gallons wax @ 3d	2	6
	27	6

That is, each ton of the coal is converted into products which realize 17/6 more than the ton of coal cost from which they were made. This 17/6 must bear capital and labor charges before the surplus is available as profit.

I desire to remind you of the variable nature of the coal being treated and of the difficulty of procuring truly represenative samples of the coal and of the fuel produced from it. Subject to that qualification the coal delivered to the retort has a calorific value of 10,300

B.t.u.'s per pound. According to Sir Thomas Hudson Beare, Professor of Engineering in Edinburgh University, the Comac fuel has a calorific value of 13,850 B.t.u.'s per pound. The fuel is bought by bakers, rivetters, welders and, of course, householders. All express the opinion that it is the best fuel known at the price. One of the industrial users of it wrote expressing his pleasant surprise to find that the ash content of the fuel was less than 5 per cent owing to its reactivity it is second to none as a gas-producer fuel.

The oil is equally good. The crude oil has a calorific value of

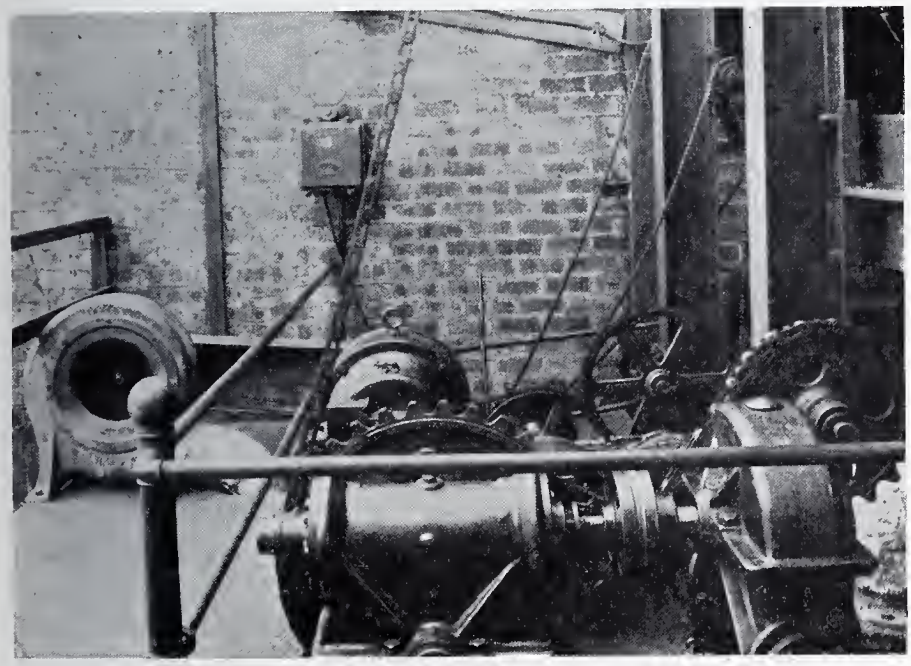

FIG. 16

17,350 B.t.u.'s. per pound. It has been used just as it comes from the separator to run Diesel and Petter internal combustion engines without alteration of any of the engine's standard fittings. No other manufactured crude oil can be used successfully in this way.

What of the future? If you have comprehended all that I have told you, you are now aware that the plant consists of various heat exchangers. Some of you will have noted that the greatest single amount of heat in the cycle is still lost. I speak of the latent heat of the steam. At present the latent heat of the steam is absorbed by a relatively large amount of condensing water. Steam can be pro-

duced from this very hot water by putting it into the closed vessel shown in this diagrammatic lay-out of a plant (Fig. 17) and reducing the pressure in the vessel by means of an air pump so causing the water to boil and to drop in temperature. In a scheme at present under consideration for the treatment of 200 tons of coal per day there will be required 20,000 pounds of steam per hour. This necessitates the provision of 40,000 gallons of condensing water per hour and quite a battery of tubular condensers. But from it could be got the 20,000 pounds of distilled water required to feed the boiler. The size and cost of this plant supplementary to the retorts compelled me to seek for a practicable alternative. I propose, therefore, to take the vapors from the retorts after passing through the wax trap into a slightly inclined locomotive type boiler (Fig. 18) and thence into the condensers. The feed water for the locomotive-type boiler will be the very hot condensing water coming from the condensers. If the steam and oil vapors issuing from the retort be at a sufficiently high temperature the steam required for the superheater can be generated from the condensing water at a pressure of 20 pounds per square inch. Or, if high pressure steam be required, I will attach to this boiler an exhauster to induce rapid evaporation by reducing the pressure on the surface of the water. The steam so produced under vacuum can be changed easily into water at atmospheric pressure and will pass to the boiler plant as de-aerated distilled water. There it will be changed into high pressure steam with which to drive turbo-alternators working at a back pressure of about 15 pounds per square inch above atmospheric pressure. The exhaust steam from the turbines will be supplied to the superheater and will pass from it into the retort. The locomotive type boiler will function solely as a latent heat exchanger. It will transfer the latent heat of the steam coming from the retort to the steam at lower temperature and pressure evaporated from the condensing water fed into this boiler. It will also convert the steam coming from the retort into water vapor before passing it on to the condensers. These now have comparatively little to do and 6,000 gallons of water per hour, that is one-seventh of that required in the former scheme, will be more than sufficient for them.

In order to reduce the initial cost of the plant I am now building a retort 10 feet in diameter. (Fig. 19). This will be provided with archimedean screws each 4 feet in diameter arranged concentrically around a steam distributing box of 2 feet diameter into which the

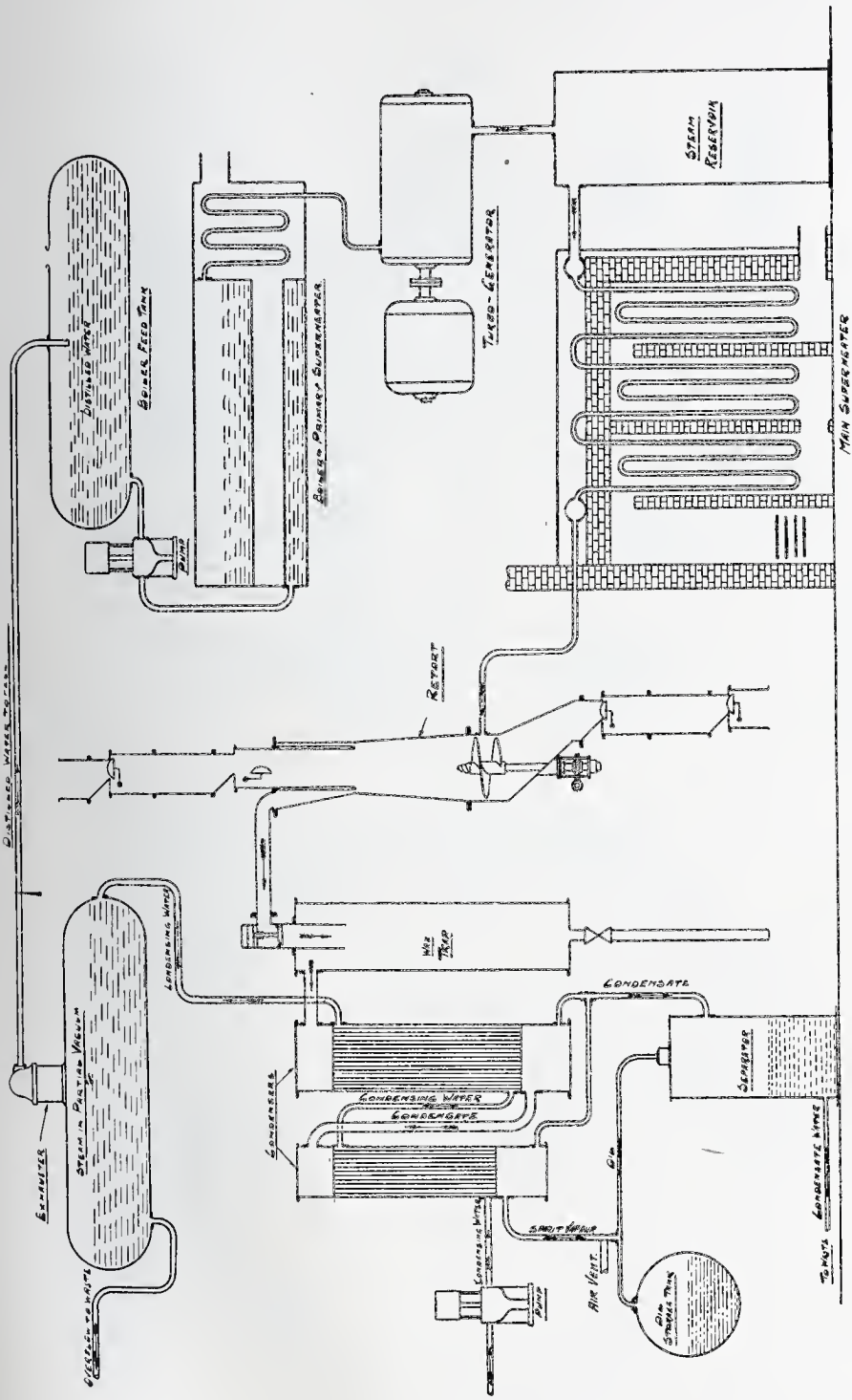
Steam Reservoir
Turbo-Generator
Boiler Feed Tank
Distilled Water
Boiler & Primary Superheater
Main Superheater
Pump
Retort
Distilled Water to Cells
Condensing Water
Condensers
Condensate
Steam in Partial Vacuum
Exhauster
Exhaust to Waste
Air Vent
Air Separator Tank
Condensate Water
To Pots

FIG. 17

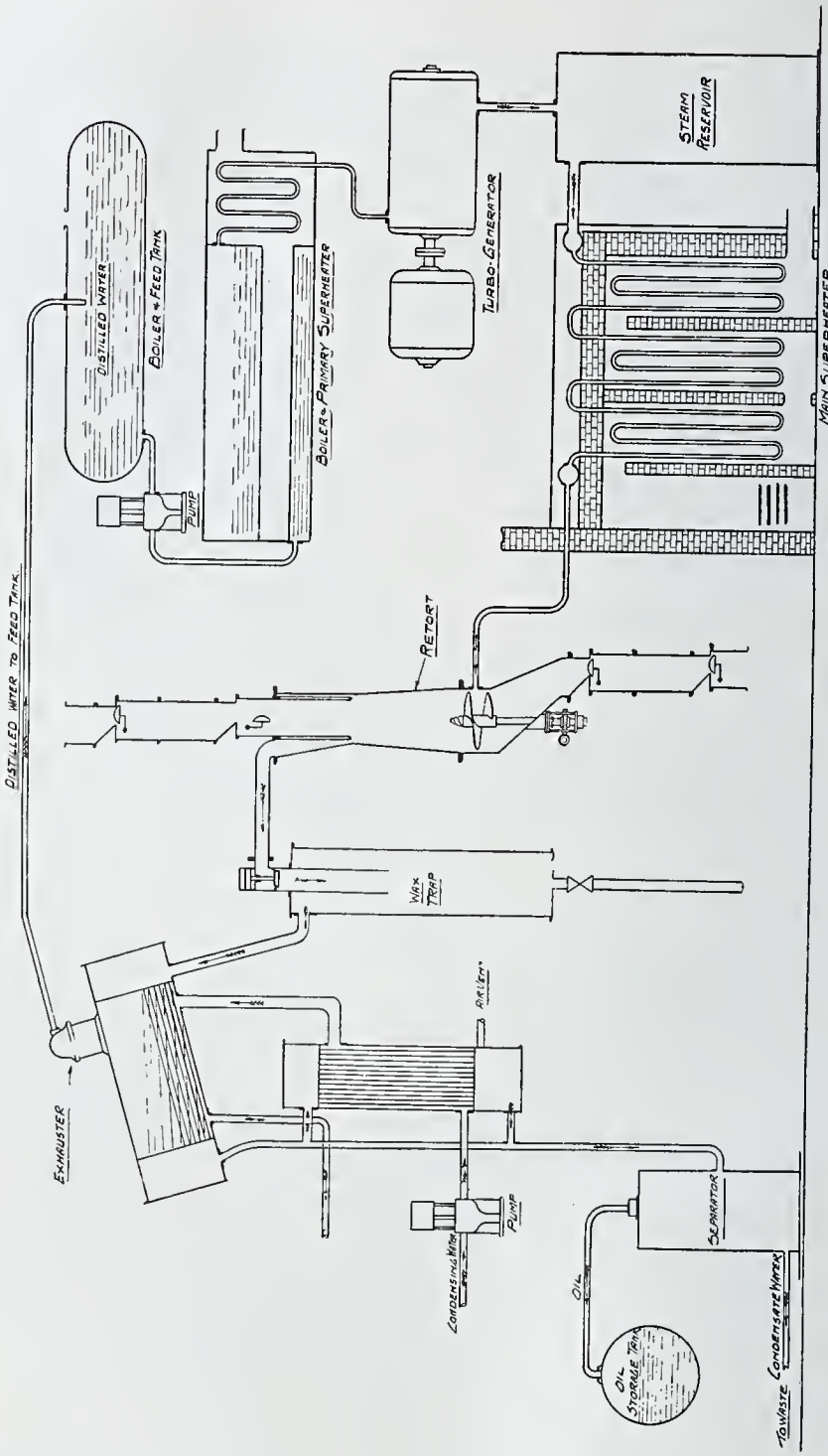
DISTILLED WATER
BOILER + FEED TANK
PUMP
BOILER + PRIMARY SUPERHEATER
TURBO-GENERATOR
STEAM RESERVOIR
MAIN SUPERHEATER
DISTILLED WATER TO FEED TANK
RETORT
WAX TRAP
EXHAUSTER
PUMP
CONDENSING WATER
OIL
SCRUBBER
OIL STORAGE TANK
TO WASTE
CONDENSATE WATER

FIG. 18

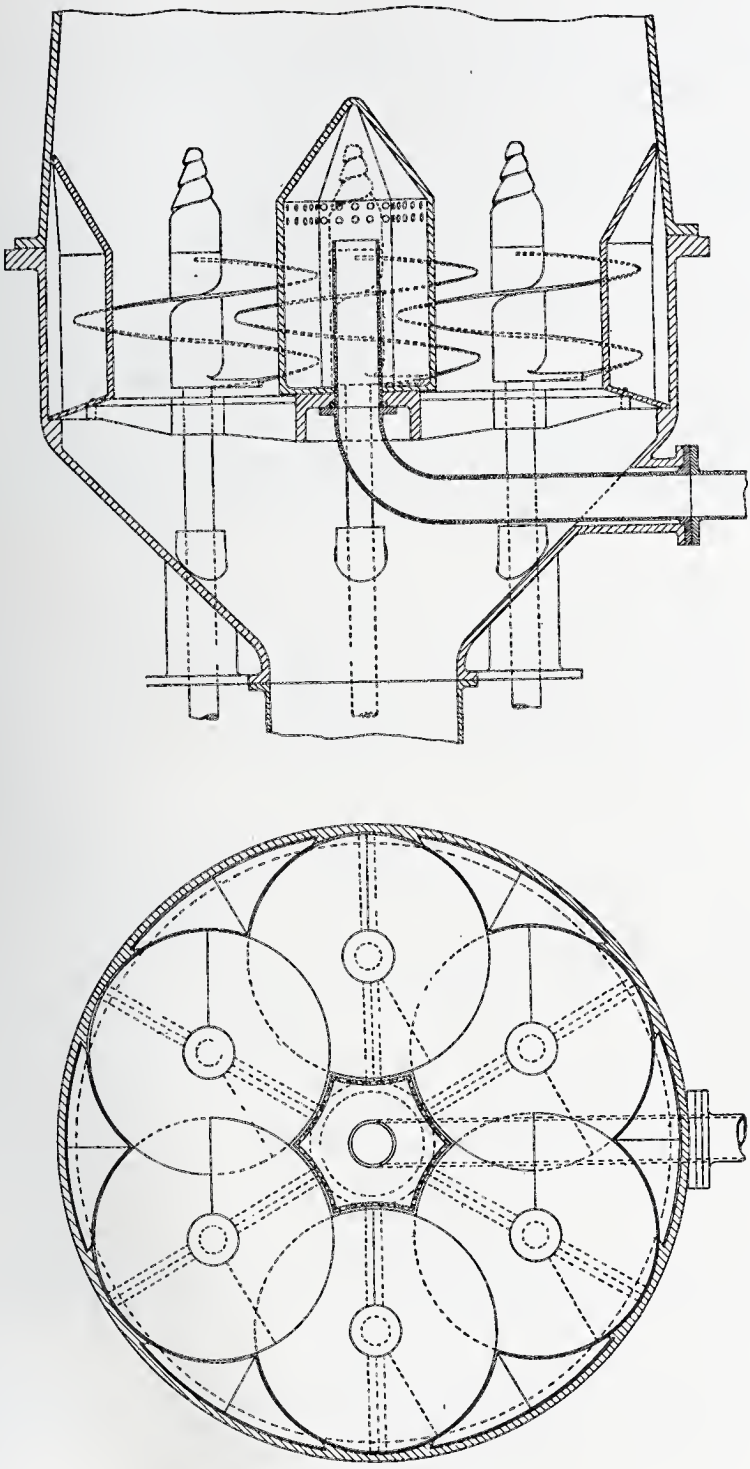

FIG. 19

superheated steam will be conveyed through a pipe below the screws. This arrangement does not involve any alteration in the present travel of the steam. This retort will have a throughput capacity about 6 times that of the present 4 feet diameter retort. It will be equipped above and below with valves identical with those of the present retort. From tests made a pair of these valves is capable of dealing with 250 tons of coal in 24 hours. From an engineering point of view this plant will be easier to make and a better job mechanically. It is estimated that a plant comprising a battery of these retorts, to deal daily with 1000 tons of average bituminous coal will cost about £200,000. If it be assumed that low-pressure steam be available in either of the above ways and that the quantities and values of the products remain unaltered, and that the coal has risen in price by 40 per cent then it will yield:

Income

400 tons No. 1 Comac Fuel at 25/- per ton	£500
150 tons No. 2 Comac Fuel at 20/- per ton	150
100 tons No. 3 Comac Fuel at 15/- per ton	75
20,000 gallons Light Oil at 7½d per gallon	625
10,000 gallons Heavy Oil at 3d per gallon	125
Daily revenue	£1,475

Expenditure

1,000 tons coal at 14/- per ton	£700
Labor	15
Interest on Capital at 5 per cent, say	30
Rates, Taxes, Administration, etc.	25
Maintenance	5
Amortization	100
Daily expenditure	£875
Which gives, as daily profit	£600
That is, as yearly profit	£210,000

DISCUSSION

WILLIAM HAHMAN (Clear Creek Coal Company, Altoona, Pa.): I would like to ask what the producers of gas do with the gas? What use do they make of the gas?

HANS SIEG (representing Dr. Plassmann): I am informed that the gas produced at present in Germany is delivered to the mains of the gas factories and mixed with the ordinary supply of water and coke gas.

CHAIRMAN REESE: Is some of the gas used for power?

HANS SIEG: No, but, of course, it can be used for power purposes.

JACQUES WEISS: Our gas is all burnt in the superheaters. In fact, we deal mainly with coals having no gas content.

CHARLES W. CUNO (Consulting Chemical Engineer, Industrial Club of St. Louis, St. Louis, Mo.): I would like to ask whether, under the conditions that steel is used, any corrosion occurs in the retorts.

MR. TURNER: In the inside of the retort, it is converted, or rather it is incased in magnetic oxide. No further change takes place. The inside of the retort looks as if it were black lead.

H. C. PORTER (Consulting Chemical Engineer, Philadelphia, Pa.): I would like to ask, in reference to the Plassmann coke, as to the gravity and density of the product, what we call in this country the apparent speeific gravity or lump density of the product.

HANS SIEG: The specific weight, as far as I am informed, is between 0.8 and 0.9.

CHAIRMAN REESE: The bulk gravity is what he wants.

HANS SIEG: A cubic meter of coke in pieces would weigh about 450 to 500 kilograms.

J. H. JAMES (Professor of Chemistry, Carnegie Institute of Technology, Pittsburgh, Pa.): I would like to ask Mr. Turner something about the character of fuel that he gets. Is it rugged, compact, or can it be easily pulverized?

MR. TURNER: That depends on the material from which it is made. It becomes a solid block, which is cut by the archimedean screw and breaks into any size desired, if it is a coking coal.

The non-coking coal passes out exactly as it went in, unless they should happen to pass in and save a sandwich of coal substance, dirt, bound with coal substance. Under these conditions, the coefficiency of expansion of coal substance differing from the dirt substance, they separate into three pieces and pass out as three pieces. The coal substance will float on water and the dirt substance will not float.

It simply depends on the raw material as to the form in which the material will pass out. On this table here, a coking coal to which I referred, went in as slack. We had difficulty in getting it through the bulk because of its mass. We put the entire mass into a bulk 18½ inches broad by 15 inches deep. It broke by its own weight overhanging in the scoop. We put coal through two bulk valves to break into a size that would drop through the valves, and so far as I can see, it has undergone no further deterioration, although it was made in May of 1927 and stood out in the open ever since.

C. W. ANDREWS (H. A. Brossert & Company, Chicago, Ill.): I would like to ask Mr. Turner why the sulphur which is in the coal will not attack the rest of his apparatus in view of using so much water. I agree with him thoroughly on the retort.

MR. TURNER: There are many things that are not known about this retort. Although I have made it and worked with it for some years, there are still some things I do not know. I do not know why sulphur does not affect it. It has no effect whatever, and I have had occasion to pull out the tubes to see how it affects them.

W. L. BYERS: I would like to ask, in regard to the C.T.G. process, if any tests were made on expanding coals when they were put under this process, and whether any tests were made as to the amount of tar and oil recovered.

HANS SIEG: So far, in all the expanding coals of Germany and England that have come through our ovens, we have found no difficulty in any shape or form of producing a good, solid, hard coke as shown here. In fact, this coke shown is made from a coal that is liable to expand very considerably.

From German coal so far we get about 5 to 6 per cent of coal oil or tar. A quite considerably greater amount is procured from English coal, which coal is of a much better quality. And the coke produced from English coal, by this process as shown on the screen, is of a much better quality than even this coke shown here.

CHAIRMAN REESE: Has this coke strength enough?

MR. SIEG: I can only state this: that the head of an important research institute stated, in my presence and in the presence of some English experts, that the hardness and density of the coke would be quite sufficient for blast furnaces of a capacity up to 100 tons, and he is sure that the tendency towards abrasion would not be too high.

In other words, he says that our coke is hard enough for any furnaces of higher capacity, but he does not know yet whether the tendency towards abrasion will be small enough in those large furnaces. He will probably make those abrasion tests very soon himself. Of course, due regard has to be paid to the nature of the iron ore.

W. L. AFFELDER (Vice-President, Hillman Coal & Coke Company, Pittsburgh, Pa.): In one of the tables in the C.T.G. process, the coke was shown to contain 8 to 10 per cent volatile and a yield of 90.6. What was the volatile from which the coke was made?

MR. SIEG: The volatiles of the coal yield were between 23 and 25 per cent.

MR. AFFELDER: I do not quite see your balance then. If your coal contained 23 to 25 per cent of volatile and your coke 8 to 10 per cent, you have lost 15 per cent of volatile. And yet you have a 90.6 per cent yield of coke.

F. C. GREENE (Old Ben Coal Corporation, Chicago, Ill.): I noticed that, but I think it is due to the fact that it washed in free material. You see, the percentage of coke seems to be about 72 to 75 per cent, or something like that, accurately.

CHAIRMAN REESE: Does that satisfy you, Mr. Affelder?

MR. AFFELDER: It still seems out of balance to me.

C. W. ANDREWS: That column, I think, Mr. Affelder, refers to what is headed "pure coal," as Mr. Greene said.

MR. GREENE: I do not notice any investment cost on this apparatus, that would lead one to get an idea of what could be done on quantity production. It seems to me that we have to get an apparatus that will put out a large tonnage for a low unit of cost, and I think that is one of the things we ought to have as much information on as possible.

I told you our unit costs here two years ago, and I am willing to say that we are as high as anybody, but I do not know of any place that is any lower.

Now if anybody has anything lower, it is going to interest somebody in this country or abroad, and I think it ought to be brought out.

MR. SIEG: The oven of the C.T.G., including heating apparatus and anything connected with the oven itself, will cost approximately $80,000 for a daily run of 65 tons of coal.

MR. GREENE: There you are. That is the same old thing. Where are those fellows with the $250 a ton today? Those are the fellows I want to hear from.

JACQUES WEISS: I said in my paper that the plant would cost about three-quarters of a battery of coke ovens of the same capacity, and you can double that figure if you know how.

CHAIRMAN REESE: The only thing you have to say is, "Know how on the small one and you know how on the big one."

CHARLES TURNER (Glasgow, Scotland): I would say that I have received a quotation for the complete plant, erected ready for work—foundations, roofs, buildings, everything—of £110,000 for 1000 tons a day.

But as in my former experience, mechanical engineers always find there is some reason why they should do something. I wanted some working capital. I have given in my paper £200,000 and of that I showed 100 per cent per annum for getting my money back in four years.

MR. GREENE: That helps a whole lot.

CHAIRMAN REESE: If you can get the figures, you can get it.

MR. GREENE: I would like to know where the $250 comes in.

L. P. ALFORD (Vice President, Ronald Press Company, New York, N. Y.): Mr. Turner said that on a million dollars investment, he would deal over 100 per cent and still return his capital in four years.

MR. TURNER: Yes, that is, taking the figures or the prices for the commodities which I am selling and have been for the last two weeks, working on a particular coke. I presume the price of coal will rise as much as 40 per cent. I admit I do not think it will rise by 40 per cent, but I assume it might, as I have had pointed out to me since I came here. Before I came here, coal was very much too cheap. Of course, I am a very difficult individual to persuade about that. The cost of production is too high.

LOW TEMPERATURE DISTILLATION OF COAL BY THE CARBOCITE PROCESS

By W. H. Allen, Jr.

Chemical Engineer, American Gas and Electric Company, New York

Introduction

The American Gas and Electric Company first became interested in the general field of coal distillation because of its possible economic value in connection with central power generating plants. After a rather exhaustive study, we reached the conclusion that in order to develop a commercially attractive low temperature distillation system, we must somehow increase the value of the coke residue beyond its bulk fuel value for stoker fired boilers. With the present day prices for by-products, it would seem very difficult to have a profitable operation if all of the coke is to be used in the power plant boilers to replace raw coal. This is especially true in our case because most of our large operations are in or near the coal fields where fuel is comparatively cheap and where there is little demand for industrial gas.

Our interest was naturally directed toward the possibilities of manufacturing a smokeless domestic fuel—a product for which there is a steadily increasing demand. While many processes have been developed for the manufacture of smokeless briquettes, we wished, if possible, to develop a smokeless fuel which would not require the complications involved in briquetting, and thus keep the cost of our product as low as possible, which would give us a broader market for the fuel. That is, we hoped to be able to find a market for our coke at prices somewhat below the cost of anthracite coal, and perhaps we might even be able to reach the consumer who is willing to pay just a little more than Pocahontas prices in order to obtain a clean, smokeless fuel having the proper burning characteristics.

For a long time, this seemed like a hopeless undertaking, but as a result of our experience with the Carbocite Process, we believe that at least it comes nearer to answering our requirements than any other method available.

FIRST TEST EQUIPMENT

In November, 1925, we undertook a series of tests with a small assay furnace designed and operated with the assistance and co-operation of Mr. C. B. Wisner, President of the Carbocite Company and inventor of the process. This rotary was 30 inches in diameter and 5 feet long—a plain steel shell supported and rotated about a horizontal axis. It was encased in a brick setting which was heated by products of combustion from an oil burner and was merely intended for batch treatment of coal samples of 100 to 200 pounds for each charge. The coal was introduced through an end opening which was then sealed up and heat was applied to the exterior of the shell as the furnace was continually rotated. The vapors and gases evolved were passed through a hollow shaft bearing to condensers, meters, etc. Provision was also made for preliminary drying and preheating in an oxidizing atmosphere.

To our great satisfaction, we found that with skillful manipulation, it was possible to produce a coke residue in multiple ball formation from all of the coals tested; which included a variety of coals from Indiana, Ohio, West Virginia and eastern Kentucky. Furthermore, with most of these coals we produced a coke of fairly tough structure with excellent burning qualities; and the by-product yields were characteristically representative of a true low temperature distillation.

In July, 1927, a semi-commercial test unit was erected and placed in operation in connection with our power station at Philo, Ohio.

DESCRIPTION OF PROCESS

The Carbocite Process consists essentially in the continuous treatment of coal in horizontal or slightly inclined rotary furnaces. Crushed coal is dried and preheated in the first rotary which we call a Thermodizer. During the continuous passage of coal through this furnace, it is gradually dried and then preheated to some 450°F. in the presence of a regulated amount of hot air passing in the opposite direction to the coal. At the coal feed end, the free moisture passes off in vapor form, together with inert gases extracted from the coal, and any excess thermodizing air. The air treatment appears to be beneficial in preventing adhesion of coke to the carbonizer shell and encourages multiple ball formation as distinguished from agglomeration into large masses.

From the thermodizer the coal flows through a coal seal to the Carbonizer rotary where the temperature is raised to 900° or 950°F. as the distillation and coking take place. At all times the charge is flowing and mixing continuously and the hottest material leaves the rotary shell at the crest of the pile and rolls to the base of the pile in small detached pieces. It is this latter action which causes the ball formation. The heating proceeds very rapidly until the plastic stage is reached where the exothermic reactions are most effective; but after the coke structure is formed, the individual masses are so much larger than the original coal granules that subsequent heating and distillation are necessarily greatly retarded. With West Virginia coking coals, we found that the plasticity had practically disappeared when the volatile matter was reduced to about 19 to 20 per cent, but if the coke was extracted at this point, it was weak and friable. When the distillation is prolonged, however, until the volatile matter is reduced to about 12 to 14 per cent, the resultant coke is tough and still dense. (About 30 pounds per cubic foot for mixed sizes over ½ inch.) Practically all of the coke is finally discharged in spheroidal form with the size of pieces ranging from ¼ inch diameter to 4 inches or even larger. The size of pieces is controllable to a great extent by regulation of heats, degree of thermodizing, rate of coking and other factors. Classification into the various commercial sizes is easily accomplished because of the shape and symmetry of the pieces. The distillation gases and vapors are aspirated from the coal feed end of the Carbonizer and as they are not diluted with inert gases and vapor from coal moisture, they are readily cooled and after the removal of liquid condensate the fixed gas has a heating value of about 800 B.t.u. per cubic foot.

Philo Experimental Plant

The Philo experimental plant as originally built consisted of two inclined rotary furnaces each 8 feet in diameter by 30 feet long, together with coal preparation equipment, a coke cooler and the necessary gas and tar handling apparatus. We purposely chose a large diameter with short length with the idea of adding to the length if the first test work seemed to justify such a procedure. The Thermodizer was located above the Carbonizer to facilitate the flow of coal. Instead of surrounding the rotaries with a stationary heating furnace, we built a small oil or gas fired furnace nearby, as

the source of heat. Each rotary has an outer steel shell and the heating gases are pumped at high velocity through the annular channel between the outer and inner shells. This channel is only 2 inches thick and both shells revolve as well as the outer insulating jacket. The heating gases are pumped in succession from the oil

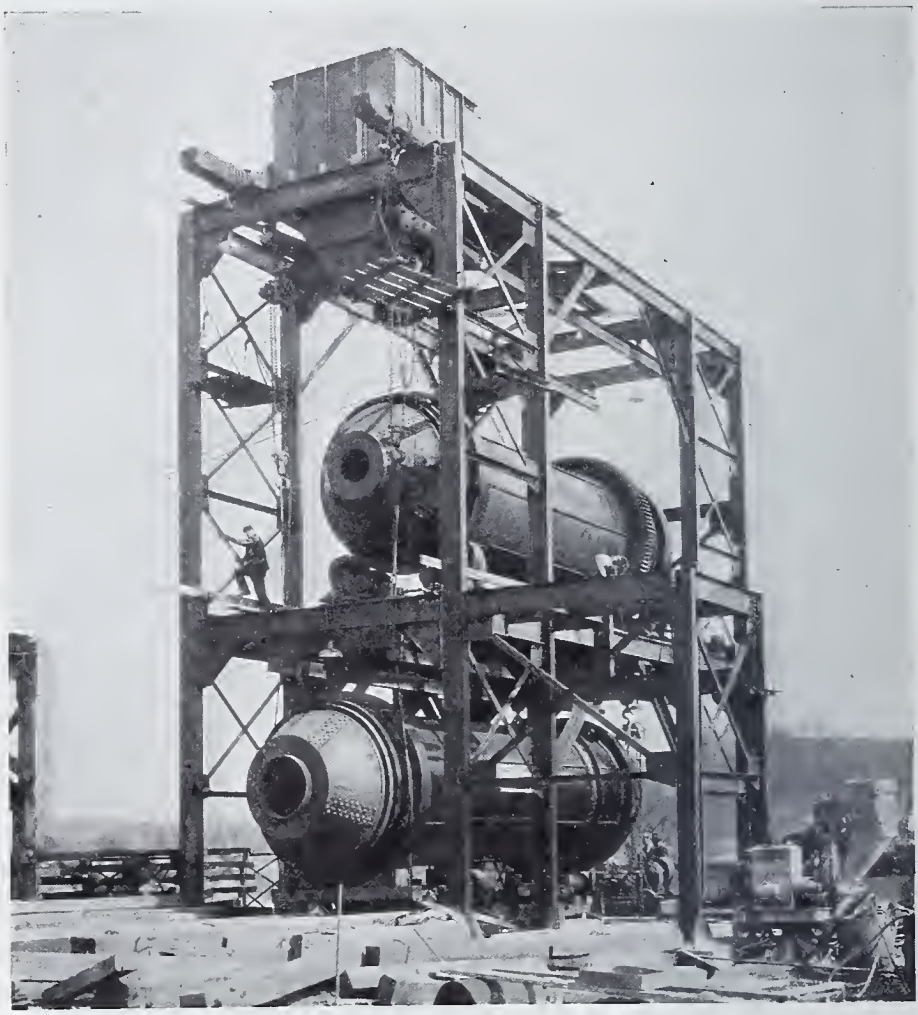

Fig. 1. Two 8 foot by 30 foot Rotors in Process of Erection at Philo

heating furnace around the Carbonizer, around the Thermodizer and through the fan to the furnace. Hot products of combustion are constantly added in the heating furnace to maintain the desired temperatures and an equal weight of waste gas is discharged at the cold end of the system.

In this plant we have concentrated our efforts on actual coke making equipment because this is the only feature which requires original treatment and special development. Equipment for coal

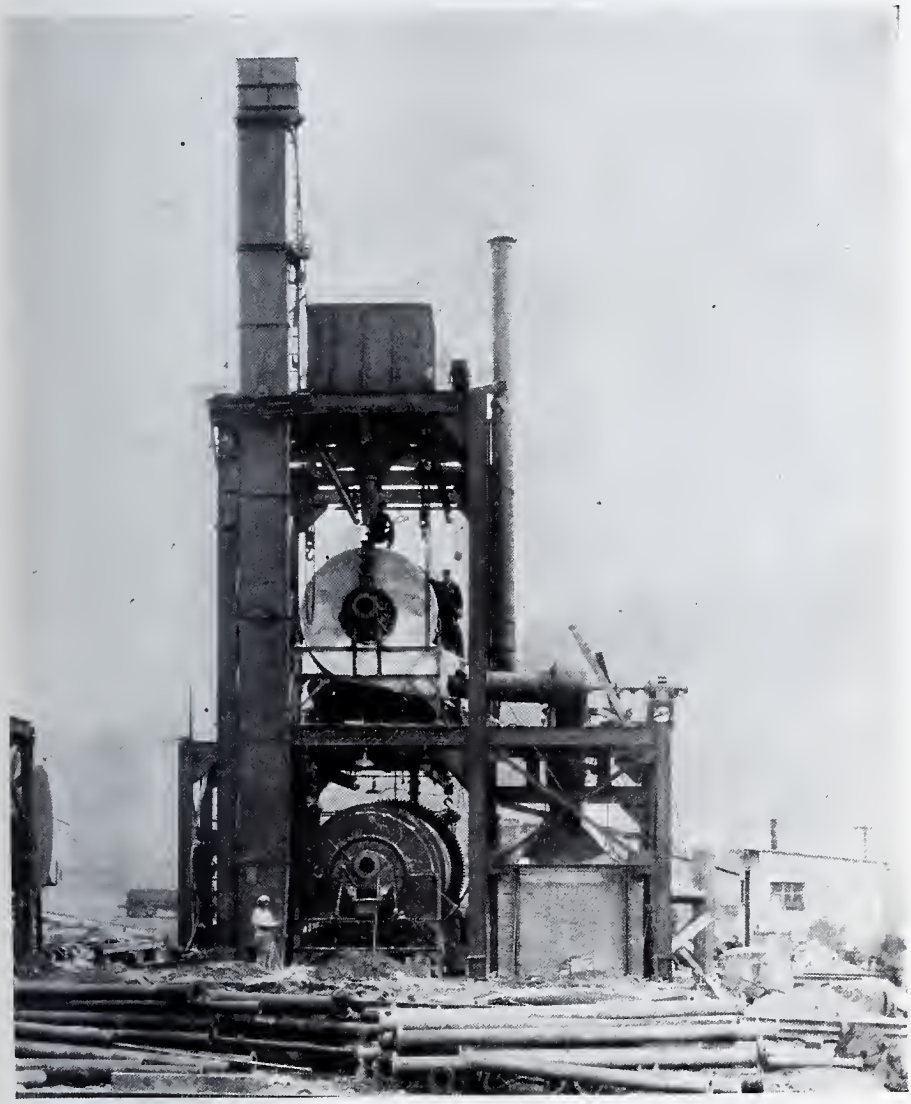

Fig. 2. End View of Rotors

and coke handling and by-product recovery is all more or less standardized and can later be provided to suit our special products when capacities are more definitely worked out.

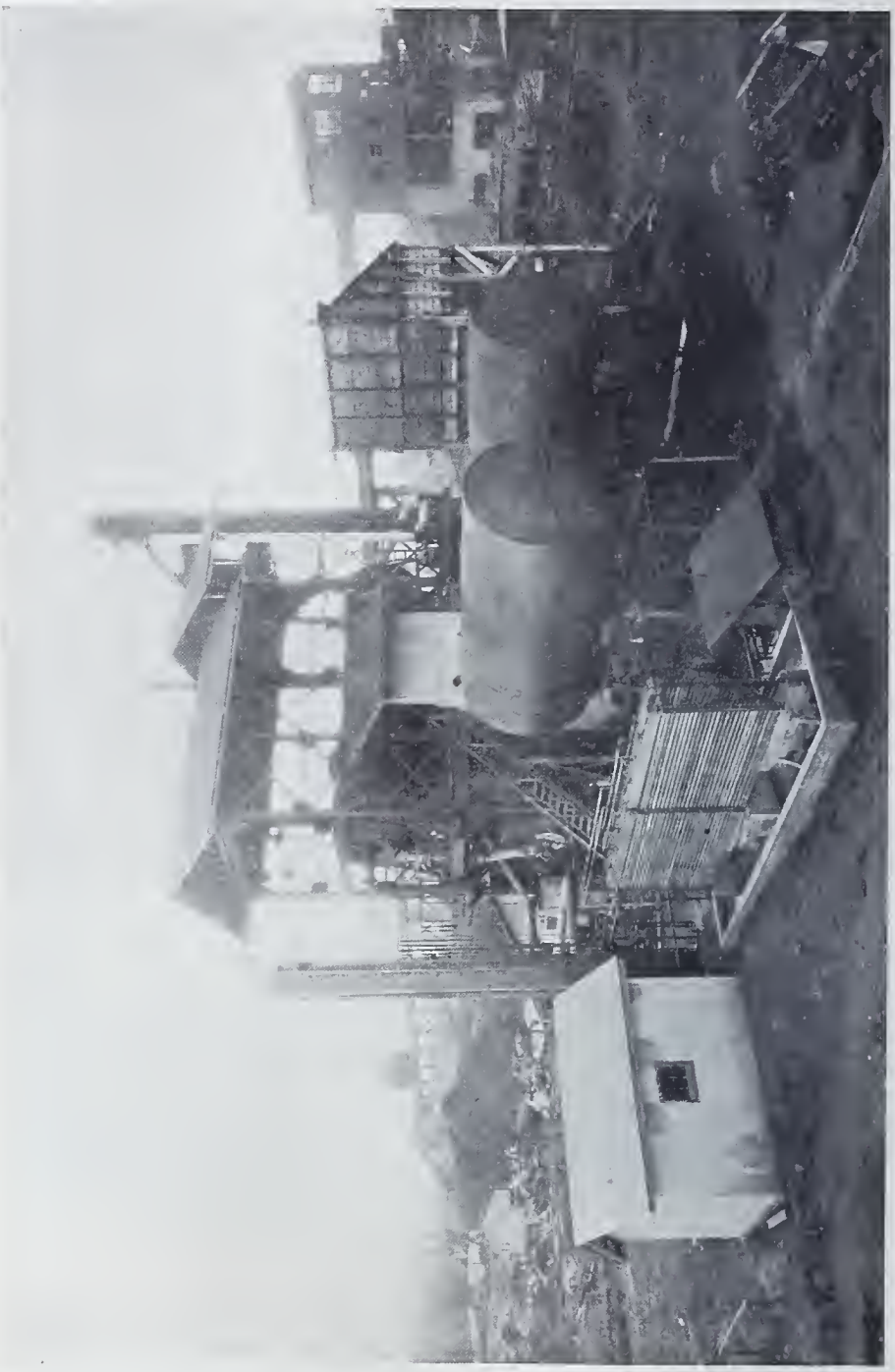

FIG. 3. TEST PLANT AFTER INSTALLATION OF GAS COOLER, ETC.

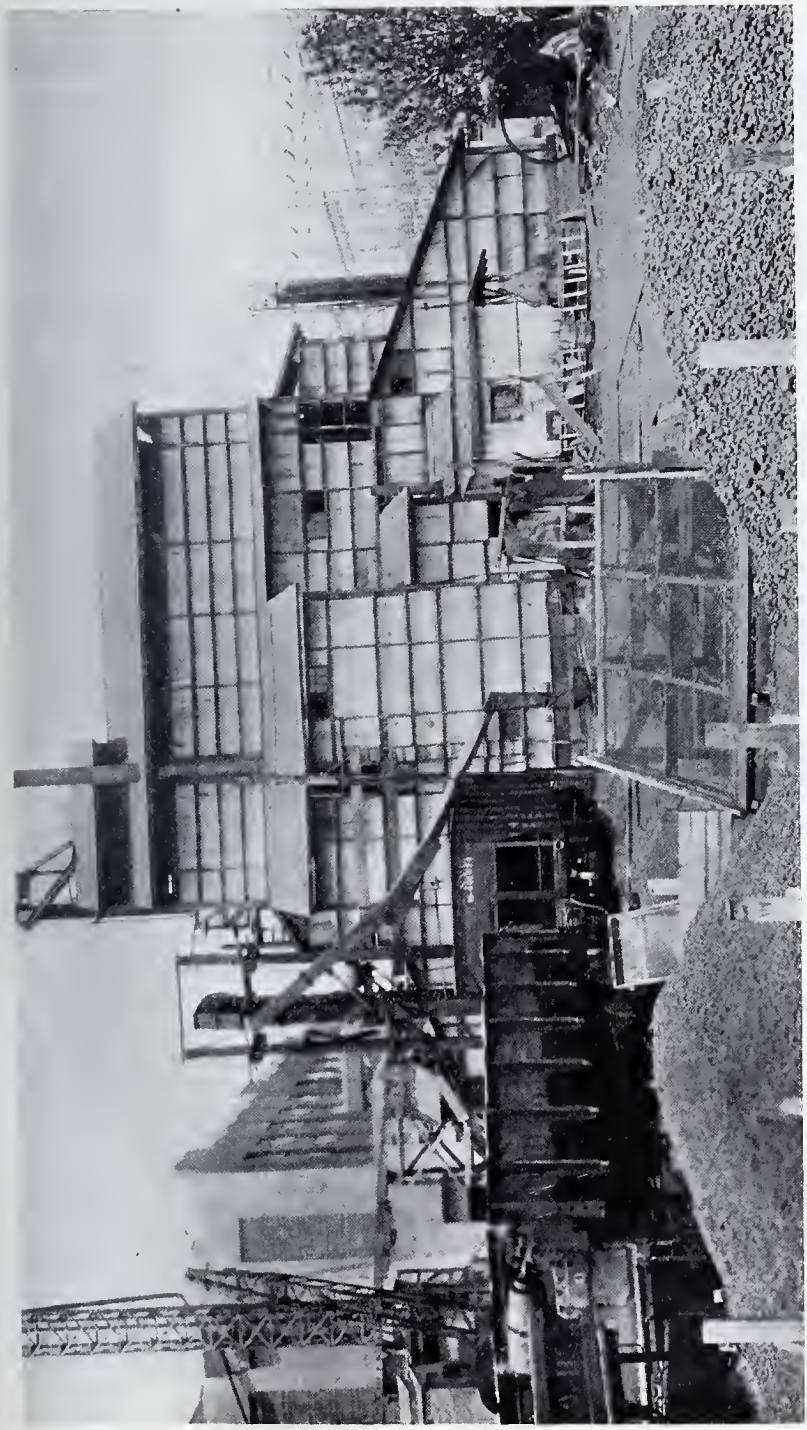

Fig. 4. Test Plant with Winter Housing Showing Coke Chute and Screened Coke in Foreground

FIG. 5. TWO SIZES OF DOMESTIC COKE LOADED FOR SHIPMENT IN OPEN TOP CAR

The coke leaves the Carbonizer through a rotary extractor which is designed to prevent gas leakage; and thence it passes through a water jacketed ribbon conveyer where it is partially cooled. It is then ready for classification into the various sizes. The hot gases and vapors at about 700°F. pass from the Carbonizer through a spray box and collector where they are cooled and enough of the light oils are condensed to hold the pitch constituents in solution. A washer cooler is provided for final cooling of the gases, and also the usual complement of exhausters, meters, etc. The raw coal is crushed with a hammer mill to such a size that 60 per cent will pass through $\frac{1}{8}$-inch openings.

Since August, 1927, we have distilled nearly 4000 tons of coal mainly from West Virginia and Ohio. The maximum capacity developed—consistent with the best quality of coke—was 43 tons of coal per day. . For two rotaries this is equivalent to a rate of 2.4 pounds per hour per square foot of heating surface. This is admittedly a low rate of heating but we are now making certain changes in the furnaces which we hope will more than offset this condition. The best results have been obtained with high volatile West Virginia coking coals, but it is possible also to make satisfactory coke from Ohio coals if the heating ean be done more rapidly.

The test plant has been shut down since the first of August for the purpose of making enlargements and improvements. The length of the Carbonizer has been increased from 30 to 60 feet and heating surface has also been added by sectionalizing this rotor. We are enlarging the coke cooler and installing coke screens and expect to resume operations some time during November.

GENERAL

It seems unnecessary to discuss yields of by-products beyond mentioning the fact that tar produced by this process shows a minimum of cracking action and that the gas while low in quantity is excellent in quality averaging about 800 B.t.u. per cubic foot in the unwashed gas. The moisture content of the raw tar after decantation is usually under 2 per cent and the insoluble matter about 3 to 4 per cent while the specific gravity averages 1.06.

The coke quality is one of the most interesting features of this process and therefore we shall try to have representative samples available for your inspection. All sizes above $\frac{1}{2}$ inch have been

shipped in carload lots from our test plant for consumption in domestic and small industrial heaters. The market reaction has been very favorable, for the coke burns without smoke, kindles readily, is reasonably clean and in a deep bed will hold the fire admirably. The average weight of all sizes over ½ inch is about 30 pounds per cubic foot. The fines under ½ inch, which constitute about 20 per cent of the coke, have been very successfully burned in the stoker fired boilers at the power plant and we believe this material would be equally well suited to a pulverized fuel installation. The heat seems to be more diffused than is the case where a high volatile coal fuel is used, because the richest oils and gases have been removed. There is no difficulty in obtaining high boiler ratings, and the slagging tendency on furnace walls and tubes is apparently reduced.

The chief difficulties encountered have been of a mechanical nature for it is admittedly hard to operate moving machinery continuously at temperatures approaching a dull red, introducing a fusible material and extracting a solid residue, and at the same time minimizing gas leakage at all of the joints and seals. The system is further complicated by the enveloping layer of heating gases which are necessarily under rather heavy pressures and suctions at various points, incidental to the high velocity required for rapid heat transfer. During the past year, however, some of the most trying obstacles have been overcome so that we are now able to operate on a more or less continuous basis.

It should be noted that this is still an experimental undertaking, or demonstration, but if we can sufficiently increase the throughput per unit of investment cost, we shall undoubtedly proceed with the installation of large operating plants. The only connection between a low temperature distillation plant of this type and the central power plant is in the economical outlet for the coke fines as a boiler fuel and in the optional provision for stocking a low temperature coke, in place of a high volatile coal which is subject to deterioration and spontaneous combustion. Primarily, the distillation plant must be located where there is a good market for the domestic fuel without encountering prohibitive freight charges; and if possible, there should be a local demand for the coal gas.

It is possible that the central power plant located near the mines may eventually form a nucleus for important industrial developments. In such a case, a low temperature operation would provide industrial gas and tar products as added inducements to the low cost of power.

THE "L AND N" PROCESS

By Harald Nielsen

Read by Robert M. Crawford, Consulting Engineer, Pittsburgh

Introduction

When I had the honor to address you two years ago at the first Bituminous Congress, I felt that the important step initiated by the Carnegie Institute would, and had to be, followed by a second Congress; furthermore, that all countries producing and interested in coal would follow the lead.

The time that has elapsed since the last Congress is short as measured by scientific progress, generally speaking, but the economics of coal production and utilization is of such vast importance and permeates so deeply into the very fabric of our civilization, that the two years have seen developments which would otherwise require decades. The economic plights of Europe have acted as accelerators to scientific investigation of coal to an extent which could not have been dreamed of two years ago.

Established processes and research work have gone forward; new processes and lines of thought have sprung up like mushrooms overnight; new companies and organizations, some good, some bad, many of them indifferent, are formed every week. If they do not all produce results commercially, the scientific work they do increases the all-round knowledge of the subject—*Coal.*

Slowly but surely the properties and characteristics and potentialities of coal are being elucidated, and we get to know some of its innermost secrets, or rather we begin to realize our limitations, and realization of this is the stepping stone to true knowledge.

Progress in Distillation

At the beginning of our work, speaking for the group I have the honor to represent here, we laid down certain definite lines on which we decided to progress, governed by what we termed the Laws of Coal Distillation—I called them the ten commandments of coal distillation. These were first made public at the Conference at Manchester held by the Smoke Abatement League of Great Britain in 1922. Since then we have done much work, attacking the subject from a great number of different sides, and we find now that today

we cannot add to nor subtract from these commandments. What we saw as through a glass darkly in those days, we can now say has taken definite shape, and our original program remains unaltered. We realized that by the method of distillation we employed, namely the passing of a large controlled volume of gases, as free as possible from oxygen, over and through coals in a rotary, inclined retort—a method now known as the "L and N" Distillation Process—we obtained various new products, solid and liquid, which had not hitherto been produced or, if produced, not recognized as such. We published and broadcast our findings and naturally came in for a good deal of destructive criticism from a number of quarters, but we managed to live through it all and stuck to our guns; and today, I am in the happy position to be able to tell you that gradually our contentions were proved and confirmed from other quarters and I believe, and have every reason for saying so, that investigators in England and other countries are recognizing the truth of our contentions.

We believed in those days that the solution for the greater part of Great Britain's coal troubles was to be found in the scientific utilization of the so-called lower grades of coal, which, if treated rationally, would give to them the right and proper position they should have in the economics of the coal world, and their true values. It is ridiculous to assert that a lump of coal, which has a market value of, say, 25 shillings per ton, should, by placing on the ground and expending energy in jumping on the coal and breaking it up, now have a value of only a fifth to a third of its former value.

It is a thankless task to attempt to make good better; good, large sized coal will always have a market and demand a fair price, in fact, it is on these grades of coals that the collieries in this country make their profits, if any. Therefore, why should I, as a colliery man, cut my own throat by competing in the domestic fuel market with a smokeless fuel produced from my own good coals by trying to convert these into a smokeless, domestic fuel at a cost. It is all very well to talk about the blue sky and ultra-violet rays—we all want this—but we want it economically, and I am afraid that this Utopia can only come about by special act of Parliament. Manufactured smokeless fuel for domestic use must be sold at a price which is considerably less than that of good raw coal, unless it is sold—as in America—in competition with anthracite. We can talk to the man in the street, who, after all, is our ultimate customer, until we are blue in the face about radiation, combustibility, reactivity, etc.—

he will not understand that by taking some of these more valuable products away from the raw coal by a highly scientific treatment, we have left him a residue which is far more valuable. He will say, "Show me the economical advantages before I give up an open coal fire which, although messy, we all love"—he will say he believes the coal fire throws out specially agreeable and soothing rays, which do him good, no hard and dry radiation as from a smokeless coke fire—he will point to his dog with its nose pushed as close to the grate as possible. Well, it is difficult to find a suitable reply to him. If he happens to know something of economics it will be still harder to convince him, he will know that from 60 to 65 per cent by weight of the raw coal is recovered as a smokeless, domestic fuel—the multitudes of published prospectuses from low temperature carbonizing companies would have educated him up to this. There is a loss in weight of from 35 to 40 per cent, which on 25 shillings represents from 8 to 10 shillings per ton; add to this conversion costs and, however cheaply the process may be operated, the smokeless, domestic fuel starts with a handicap difficult to carry, let alone to turn into a profit, unless the by-products can be absorbed in the existing gas and oil enterprises at remunerative values. If the man should be so far advanced as to read the official publication issued by the Fuel Research Board of Great Britain and ascertain the gloomy opinion of that body as to the values of the oil, or rather tar and the quantities which they state on their own authorities can be obtained per ton of coal, can you wonder that he loses heart when officially informed that the future welfare of this country lies along the lines of production of a solid domestic fuel?

I believe enough has been said to indicate that the subject of coal must be approached with an open mind and that it is futile to select one single part of this vast problem for elucidation without considering the aspect of the other equally if not more important issues.

The scientist has in the study of coal a chance, the biggest the world has ever seen.

How rightly Sir William Bragg, in his presidential address at the British Association recently, summed up everything that matters in the economic life of this Empire, when he inferred that, in scientific slang, the Scientist is the catalyst which accelerates the reactions between Capital and Labor in the right direction for the good of the community. The worst catalyst poisons are preconceived ideas and work in narrow conservative grooves in conjunction with intolerance of anything new.

Exothermic Reactions of Coal

An observation which was made very early in our work on the distillation of coal was that apparently the oil was liberated from the oil yielding substance in the coal at temperatures very much lower than those which have hitherto been quoted. We found, for instance, at temperatures from 180° to 230°C. traces of oil would be obtained from most carbonaceous materials, be they peat, brown coal or black coal. From independent quarters this observation has subsequently been confirmed.

We ascribed this fact to the action of the large volume of heating gases, which we employ for the distillation, in lowering the partial pressures of the oils set free by the thermal decomposition of the bituminous or oil-giving matters in the coal. This brought us to the idea that perhaps reactions could be detected in the coal at considerably lower temperatures than hitherto observed, and in the early part of 1926 we published some observations which clearly indicated that this was the case. We found, in fact, definite evidence that when coal was heated up to temperatures between 150° to 250°C. exothermic reactions took place, which, of course, was evidence of chemical activity.

Before this time, however, experiments carried on at Sheffield University with a small quantity of powdered fuel gave indications of a similar nature, but it was very doubtful whether the increase in temperature observed could be traced back to exothermic reactions by internal chemical activity or merely the oxidizing of the finely divided coal in conjunction with heat generated by the absorption of gases on the large surface exposed—principally admission of oxygen and oxidizing generally.

In order to eliminate any doubts on this score several large cubes of coal, each weighing between 400 to 500 grams, were cut from various seams of coal containing as little ash as possible, and a number of holes within a distance of about one centimeter of each other were drilled right into the center of the coal, maintaining the same distance from the top plane of the cube (Fig. 1). These cubes were placed in a specially designed air oven and specially made bulb thermometers were placed in each hole—the temperature in the oven was raised as quickly as possible to the desired degree by means of externally applied heat, starting at 150°C., stretching over a period of seven to eight hours and the readings of the thermometers noted at set inter-

vals. It was found that after five to six hours gradual heating a flow of heat took place from the interior towards the exterior of the coal cube. This, although indicated during the experiments at 150°C., was much more pronounced at about 200°C. and that after the lapse of three hours only. In the test carried out at 200°C. the temperature of the coal cube after four hours run was actually higher than the temperature of the oven itself. It was impossible to carry out the experiments on the coal cubes at temperatures exceed-

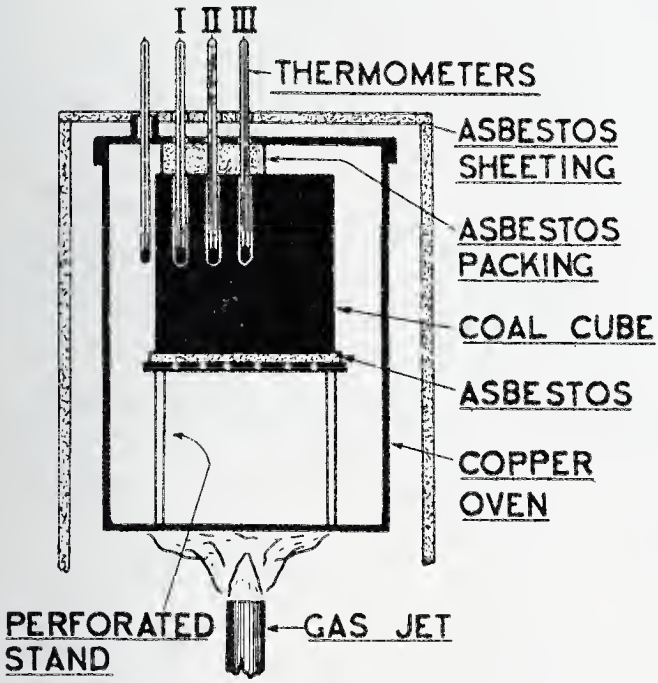

FIG. 1

ing 250°C., since the cubes began to crack and to continue in these circumstances would have served no useful purpose (Fig. 2).

In plotting the temperatures against distances from the outside of the cube towards the center, we obtained a set of curves which indicated the fall in temperature from the outside to the interior of the coal after a given length of time until the exothermic reactions took place and became predominant (Fig. 3).

The difficulty of estimating with any accuracy the conductivity of coal, therefore, becomes apparent, since the driving force in heat transfer is the mean temperature differenee between the heating

medium and the material to be heated—it will be seen that gradually, as the heating proceeds, the temperature difference becomes rapidly less and less until the temperature is reached where the exothermic reactions begin to take place, when it is found that the temperature difference for some time will remain nil, and consequently, theoretically speaking, there is no heat transfer at all. This so-called critical temperature will, according to our observations, commence be-

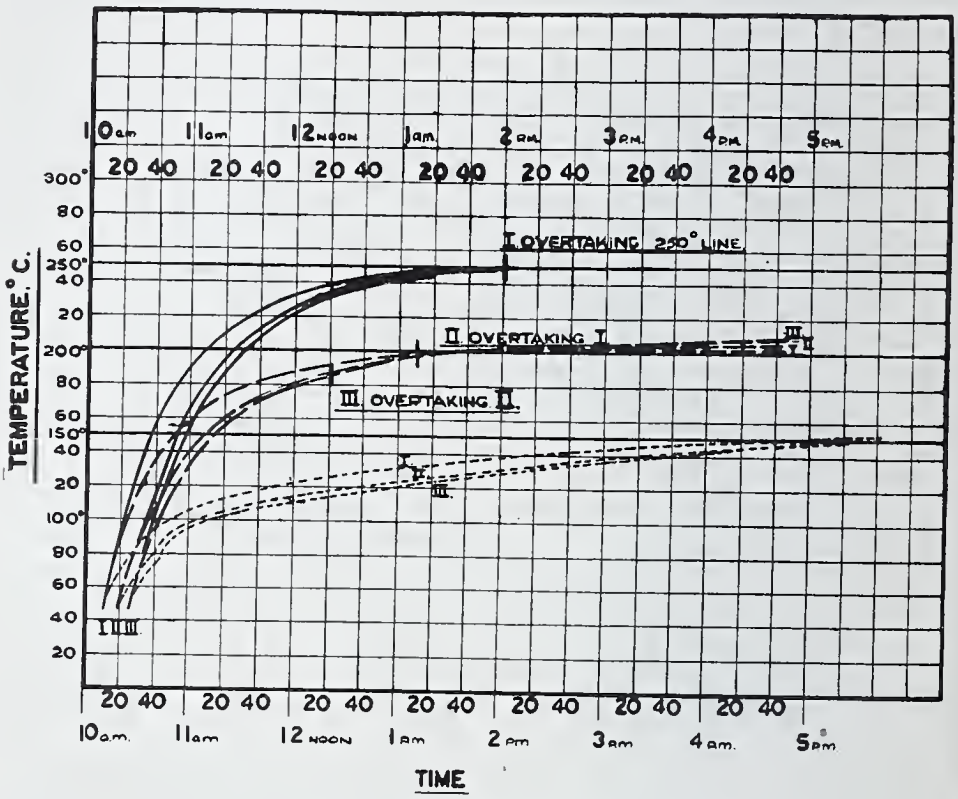

FIG. 2

tween 180° to 250°C., or, in other words, the temperatures at which we begin to observe traces of oil.

We must, however, say that in heating the coal cubes we did not observe any traces of oil but only signs of chemical activity which undoubtedly pointed to the formation of some new substance or other, of the breaking down of the existing order of things.

By lowering the partial pressures of these newly formed oily substances by employing a large volume of heating gas internally applied,

it is possible to volatilize these newly formed substances and recover them in the form of oils on subsequent condensation.

I will admit that the heating up of large cubes of coal is not exactly what would be carried out in practice.

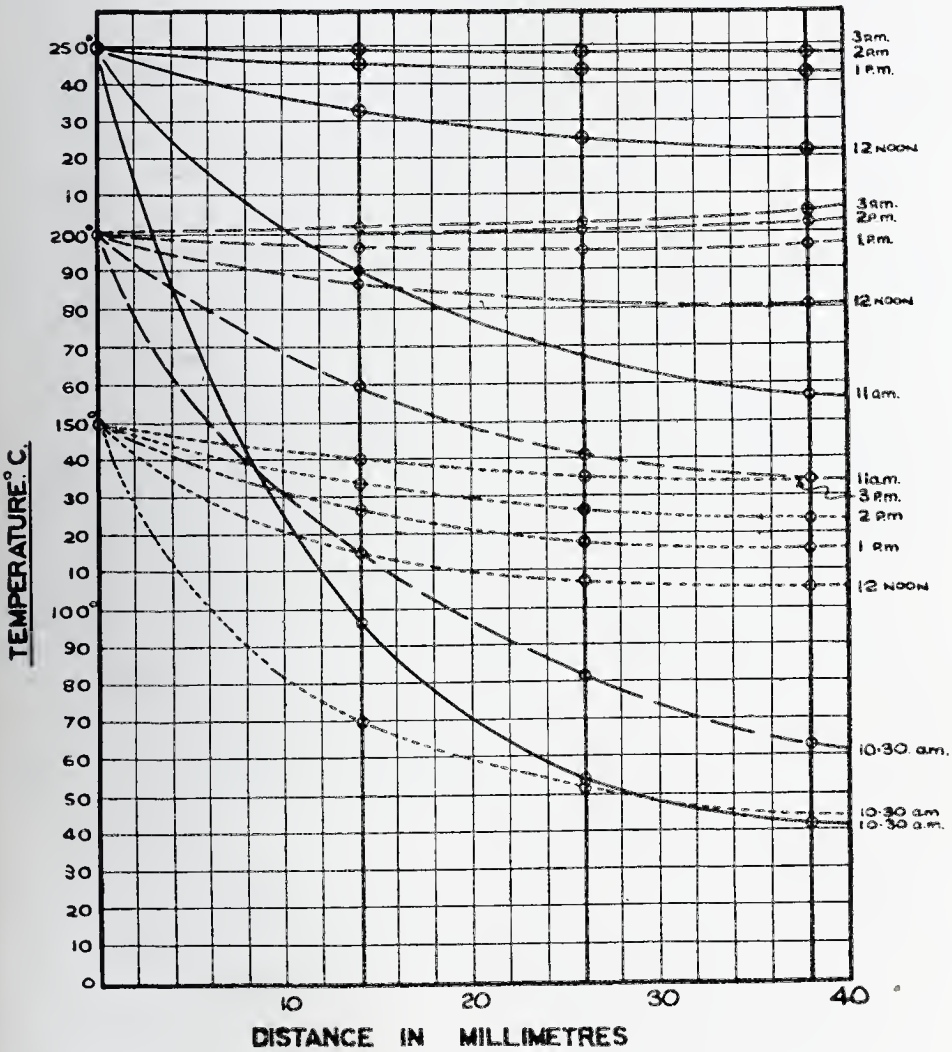

FIG. 3

PRIMARY OILS

The advantages of starting with a uniform primary product will, I think, be obvious to everybody. How this new fact elucidated will influence our work on fractional condensation, which I shall refer to

later, I cannot say at present, but it must be borne in mind that the oil I mention here was all condensed together and the analysis is the analysis of the mixed oils or the crude primary product.

I have shown, and I believe I am right in saying so, that all uncracked primary neutral oil products from bituminous coals are identical when they are produced under identical distillation conditions; furthermore, that the indications are that the oils given off in the beginning of a distillation are the same as those given off in the latter stages. We have found that the oils produced under similar distillation conditions of time, temperature ranges, etc., in our little assay plant, dealing with only from 600 to 1,000 grams at a charge, are identical with the oils we obtain by large scale tests in our testing station from many tons of coal dealt with in our retort, distilling from 5 to 10 tons of bituminous coal per 24 hours. We find now that the oils we obtain by our large retort, dealing with 100 to 140 tons of coal per day, are also extraordinarily similar to the oils obtained with the two former apparata. This, therefore, seems to prove my contentions that as far as a single coal particle is concerned when distilling under the proper conditions, employing internal heat, and provided the distillation conditions—that is to say, time, temperature, gas volumes—are identical with reference to the particular coal particle, the result must always be the same, irrespective of the size of the plant, whether the coal itself is contained in a tube of 4-inch diameter, as in an assay apparatus, or in a 9-foot diameter tube, as in our big retorting units.

In the past, and in a great many quarters even today, various contradictory opinions existed and do exist regarding the nature of the oil given off by the coal substance during distillation, or heat treatment, to use a more correct term.

We find investigators from official bodies maintaining that the properties of tar can still vary, given a constant carbonizing temperature—here is probably meant identical distillation conditions—with a retorting system and even in the same system fairly wide variations are possible which are "*entirely due to the nature of the coal treated.*"

In the *Gas Journal* of June 16 and also of the 23d and 30th, 1926, I went into considerable detail in order to discount this statement, and I continued in the *Iron and Coal Trades Review* of March 25, 1927.

I do not believe for one minute that the coal substance itself has anything to do with the matter—I believe firmly that the heat treatment is the all-important factor.

My views were confirmed by the work carried out by Mr. R. A.

Strong of the Canadian Bureau of Mines and published in its Report No. 671 of 1927. He examined various kinds of bituminous coals from Canada along lines very similar to those adopted by myself, and he states, on page 81, the distillation results of the neutral oils from the regular carbonization series. Comparing the oils from the three coals tested at the same temperature and by the same method of carbonization, it will be noted that the three coals gave neutral oils with quite uniform distillation ranges, the difference in the three curves being less than the usual difference noted with a crude petroleum. This, he continues, agrees with Nielsen's claim that all neutral oils from bituminous coals are identical.

In my paper at the last Pittsburgh Conference, on page 680, Table No. 6, I drew attention to the remarkable similarity between the neutral Fischer fractions of Canadian lignite and German brown coal oils and the corresponding Fischer fractions from British bituminous coals. I hinted that apparently the neutral oils would be identical. This tentative suggestion seems to be fully confirmed by the work carried out by Dr. J. Herzenberg, from the Institute for Brown Coal and Mineral Oil Research of the Berlin Technical High School. On page 628 in the German periodical *Braunkohle* of July 14, 1928, he gives ultimate analyses of the neutral fractions from German brown coal corresponding to the Fischer fractions mentioned above, and states that he found the oil contained *86.48 per cent* carbon, *9.19 per cent* hydrogen, *3.82 per cent* oxygen—further comments seem superfluous.

The mechanism of the oil formation in the coal substance is still a deep mystery to us, but one of these days we shall see more clearly.

Individually our knowledge may be slight, but collectively I believe we know something, and this is my reason for advocating scientific collaboration in the widest sense.

With a view to ascertaining some data regarding the oil given off by the coal at the various temperatures and at the various distillation stages, we carried out a series of tests in our laboratory. We employed the type of assay apparatus which I described in my last paper for the Carnegie Institute, as well as a slightly modified apparatus embodying exactly the same distillation principle as before, the only difference being that the coil and the container were completely immersed in a lead bath in order to keep the distillation temperatures as constant as possible.

Dealing with fairly large quantities of coal—about 600 grams at a

charge—we found that in spite of every possible care we could not maintain the temperatures throughout the coal mass with less variation than 15° to 20°C., but we decided to continue our work. We made up our minds to divide the coal distillation into two distinct stages—in the first stage we carried through a number of distillations and collected all the oils which were given off by the coal substance, from the first oil indications up to 380°C. For this work the lead bath apparatus was used. The assay apparatus was then removed from the lead bath and placed in the ordinary gas heated furnace, and the distillation was carried up to as high as possible, namely, 660°C. It will be understood that the coal charge during the change in operations was not removed from the actual apparatus or container itself. The oil given off between 380° to 660°C. was now collected; we examined the oils, analyzed and measured the gas given off and Table I gives the results.

It appears that the specific gravity of the crude oils as well as the neutral oils from the various stages are almost the same within the experimental error. I attribute the slight discrepancies to the imperfect apparatus and manipulation.

Coming to the ultimate analyses of the oils and judging by the hydrogen percentage, which, to my mind, is the only comparatively safe figure to go by, the oils do appear to be identical. The percentage of neutral oils also seems to be the same within 1 or 2 per cent. Anybody accustomed to this kind of work will realize how very difficult it is to obtain agreement within a fraction of a decimal.

The tar acids are also very interesting and show extraordinary similarities. It appears, however, as if the oxygen contents of the tar acids given off at lower temperatures seem to be somewhat higher than the oxygen percentage of the tar acids evolved at higher temperatures.

It may be said that the cuts were too crude, since we only dealt with two fractions, namely from the beginning up to 380°C. and from 380°C. up to finality; we, therefore, made steps to obtain the first few cubic centimeters of oil collected in our condensers. We collected a few cubic centimeters from a number of assays on the same coal and subjected the oil thus collected to the same examination as the two first oil fractions and we found the figures given in Table II.

Here again I must say that indications point to the first oil given off by the coal during heat treatment being similar to the oils obtained at a much later stage and even at the considerably higher tempera-

tures. The tar acid percentage, however, seems to be somewhat higher, being 57 per cent as against about 40 per cent, but I should

TABLE I

		RETORTING TEMPERATURES	
		Oil up to 380°C.	Oil between 380° to 660°C.
1	Percentage of total oil yield	45.0%	55.0%
2	Percentage of light spirits	None	2.4%
3	Solid residue (semi-coke)	77.5%	59.5%
4	Gas volume per ton of coal	52 cu. ft.	2000 cu. ft.
5	Gas volume per ton	1.48 m^3	57.1 m^3
		Volume percentages	
6	Analysis of permanent gas:		
7	$CO_2 + H_2S$	22.8%	9.8%
8	CmHn	3.4%	3.2%
9	O_2	1.4%	0.1%
10	CO	10.6%	10.1%
11	H_2	6.3%	33.4%
12	C_2H_6	12.7%	8.4%
13	CH_4 + loss	12.5%	31.2%
14	N_2	30.3%	3.8%
15	Specific gravity of dry oil @ 15.5°C	1.049	1.057
16	Carbon	80.6%	82.1%
17	Hydrogen	8.6%	8.5%
18	Oxygen	10.8%	9.4%
19	Per cent of neutral oils	58.0%	60.0%
20	Specific gravity @ 15.5°C	1.000	0.998
21	Carbon	85.4%	86.5%
22	Hydrogen	9.1%	9.2%
23	Oxygen	5.5%	4.3%
24	Per cent of tar acids	42.0%	40.0%
25	Specific gravity @ 15.5°C	1.093	1.084
26	Carbon	77.2%	80.7%
27	Hydrogen	7.7%	7.8%
28	Oxygen	15.1%	11.5%

not place too much reliance upon those figures, since it is difficult to determine the tar acid percentage with great accuracy when only small samples of oils are available. I, therefore, feel inclined to go

one step further and say that the neutral oils from coals, that is various kinds of bituminous coal from various seams, various districts and various countries, are not only identical, but the true primary oils which have not been subjected to secondary decomposition are also identical throughout the distillation period and that the first oils obtained are extraordinarily similar, not to say identical, with those obtained during the latter stages of the distillation or heat treatment. This observation to my mind is quite an interesting one and may throw some light on the evolution of oil in the coal substance itself.

We have at present not done sufficient work on this to furnish any

TABLE II

ANALYSIS OF FIRST FEW CUBIC CENTIMETERS OF OIL DISTILLED OVER FROM THE RAW COAL AT COMMENCEMENT OF TESTS

Specific gravity of crude oil @ 15.5°C	1.037
Carbon	81.4%
Hydrogen	8.6%
Oxygen	10.0%
Per cent of neutral oil	43.0%
Specific gravity of neutral oil	1.000
Carbon	84.9%
Hydrogen	9.6%
Oxygen	5.5%
Per cent of tar acids	57.0%

further facts, but no doubt, in other and more capable hands, the indications I have given here may produce more fruitful results.

I may say that in considering the steps from 0.6 to 1 kgm. up to 5 to 10 tons this step is naturally greater than from 5 to 10 tons up to 150 tons a day. We have, therefore, not reached finality with the 100 tons unit. Our German associates are now designing plant to deal with 300 tons a day in a single unit, but say this is not going to be the limit.

Already in brown coal drying practice in Germany units capable of dealing with 600 tons of brown coal per day, and drying same from 50 per cent moisture down to 10 to 12 per cent, are in operation. The work carried out in these apparata is much greater than that of distilling the corresponding quantity of coal.

It must be realized that the main thing we have to do is to bring the heat into the most efficient contact with the coal and to do this we require a very large surface; and what heating surface can be larger than that of the actual coal itself?

I have shown previously the difficulties in forming a picture of the heat transference and how the exothermic reactions in the coal attempt to hinder the heat transfer—the larger the coal the greater the difficulty. We must, therefore, go to the other side and deal with small coal only. I may say, however, that I believe firmly that there is a practical limit to the fineness of the coal to be dealt with and I do not believe in the distillation of a very finely powdered material, for the reason that the cost of fine grinding must always be included in the operating costs of the plant and, secondly, dust troubles in the tar or oils are bound to occur, and, thirdly, because of the unknown action of the surface tension when the surface approaches infinity in proportion to the amount of oil available.

IMPORTANCE OF VOLUME OF DISTILLING MEDIUM

In this paper I am dealing principally with the oil side of the distillation. My reasons are that the oils show most profoundly the changes in heat treatment and give the surest indications of the conditions of distillation. Considerable work has been done in other quarters on oil produced by externally heated retorts; that is to say, on products which have suffered more or less extensive secondary cracking and decomposition. On oils produced by internally applied heat very little has been published, with the exception of the Reports of the Canadian Bureau of Mines and one or two German investigators, outside the facts and figures supplied by the group with which I am associated. Quite recently we decided to ascertain whether by the employment of very large volumes of distilling medium—in fact impractically large volumes—some differences could be detected in the primary oils when compared with the primary oils on which we have hitherto worked. Incidentally, we desired to know if the possibility existed of obtaining some definite data regarding the heat which had to be provided in order to distill bituminous coal at low temperatures.

The coal we operated on was the same as that on which we conducted our distillation tests mentioned above, the only difference being that, where we used grams before, we now dealt with tons.

Table III gives the analytical data of the coal.

One of the most striking observations was that the temperature of the distilling medium was not as important as the "time factor;"

TABLE III

	AS RECEIVED	DRY, ASH FREE
Proximate analysis:		
Moisture	12.7%	
Vol. matters	38.1%	47.0%
Fixed Carbon	42.9%	53.0%
Ash	6.3%	
Ultimate analysis (dry basis):		
Carbon	73.2%	78.9%
Hydrogen	5.0%	5.4%
Oxygen	11.9%	12.8%
Nitrogen	1.3%	1.4%
Sulphur	1.4%	1.5%
Ash	7.2%	
Calorific value:		
B.t.u. per pound	11.240	
Kilogram calories per kilogram	6.250	
Distillation yield as received:		
Solid residue	59.00%	
Oil	8.25%	
Gas	3.35%	
Free moisture	12.70%	
Combined moisture and loss	16.70%	
Calorific value:		
Per ton coal	6,250,000 kgm. cal.	
In solid residue	4,160,000	
In oil	790,000	
In gas	220,000	
Total latent heat recovered in products	5,170,000 kgm. cal.	
Thermal loss	1,080,000 kgm. cal.	
Equivalent to	17.28%	

that is to say, the period of time in which the liberated oil particle is in contact with heat.

Another observation was that the oils crack or decompose at much lower temperatures than generally believed possible, provided the time factor is greater; or, in short, the rapidity of withdrawal of the oil vapors from the heated zones must be greater than had previously been considered necessary if cracking is to be avoided. This has been recognized in a general way for quite a long time, but I do not think that it is known that it is only a matter of seconds before irreparable damage is done to the oil. We distilled the coal by employing a gas volume equal to 2 cubic meters per kilogram and the data observed are plotted in Figure 4, curves B. We have found that this gas volume is the most economical commensurate with an excellent oil quality. A smaller gas volume, about 1.2 cubic meters per kilogram of coal, will suffice to carry the necessary heat, but the time factor is too great, hence the oils are unsatisfactory. I shall revert to the heat volume later on.

In the comparative tests, a gas volume of 7 cubic meters per kilogram coal was employed, and the observations are plotted in Figure 4, curves A.

Figure 4 also shows the Engler distillation curves, as well as the specific gravity curves of the crude anhydrous and neutral oil fractions at 155°C.

The gas inlet temperature to the retort was in both series of tests of the magnitude of 600°C. The gas outlet temperature in the first case was maintained at 250°C. minimum, and in the latter case very considerably higher. In order to arrive at the total yield of lighter oils produced when distilling with 7 cubic meters per kilogram coal, an activated charcoal filter was employed after the condensers so as to remove all condensible and absorbable oils.

It will be seen from the figures that only a small proportion of the crude oil is represented by motor spirit—that is oil boiling below 200°C., namely 1.7 per cent by volume, and only traces at 170°C.

The Engler distillation was carried up to the point where decomposition of the oil was observed to commence—particularly careful observation was made here. Permitting a decomposition loss of the usual 3 to 4 per cent, the distillation could be carried up to 400°C. but the high boiling viscous oils would stand to suffer by this more radical treatment.

There is a distinct difference in the distillation curves even after making allowances for the higher percentage of lower boiling fractions in the oil obtained from the test in which the gas was scrubbed by

activated carbon (i.e., the 7 cubic meters per kilogram test). The distillation curves from 290° and upwards only vary within 1 to 1.5

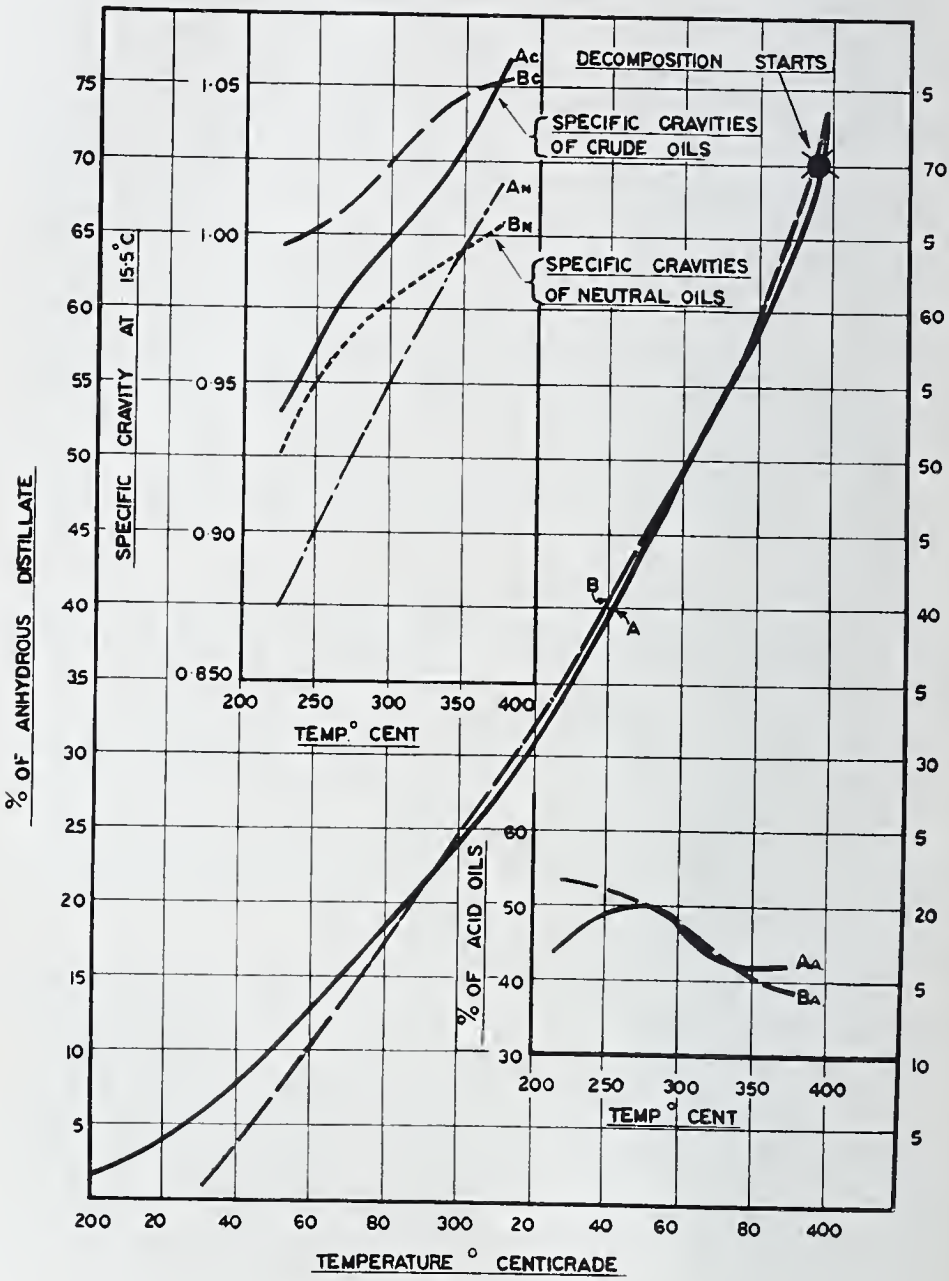

FIG. 4

per cent but the specific gravities of the neutral oils show pronounced differences, and whereas the neutral oil produced by the large gas

volume has a specific gravity curve approaching a straight line, the other is curved, indicating a thermal decomposition.

According to the Fischer test (see the book by Professor Franz Fischer, *Die Umwandlung der Kohle in öle*), both oils are excellent, well within the Fischer limits, and the petroleum solubility is complete in both cases and the decomposition points are very close.

The question may rightly be asked, when the oil produced by

TABLE IV

	2 M^3 GAS PER KILOGRAM COAL	7 M^3 GAS PER KILOGRAM COAL
Fischer analysis:		
Specific gravity of 200° to 300° fraction @ 20°C.	0.936	0.911
Specific gravity of fraction above 300° @ 50°C.	0.993	0.987
Solubility in light petroleum	Complete	Complete
Ultimate analysis of Fischer 200° to 300° fractions:		
Per cent carbon	86.8%	86.3%
Per cent hydrogen	10.4%	10.3%
Fischer oil above 300°C.:		
Per cent carbon	87.6%	86.9%
Per cent hydrogen	10.2%	9.7%
Per cent of crude oil soluble in light petroleum:	31.9%	38.8%
Alkali soluble (tar acids)	13.2%	19.3%
Acid soluble (bases)	Under 0.05%	0.1%
Specific gravity of soluble oils @ 15.5°C.	1.000	0.994
Decomposition of crude oil commences at	374°C.	386°C.
Setting point of fraction 350° to 380°C.	28°C.	29°C.

employing a very large volume of gas appears to be superior to that produced by a lesser volume, why not then use the large volumes? Theoretically, everything speaks for it; practically, there are difficulties however.

First, there is the question of heat economy. The gas used as the distilling medium must enter the system at a certain minimum temperature, about 600°C.; otherwise the temperature difference be-

tween the heating gas and the coal is too small for efficient heat transfer. The amount of heat required to distill coal is something on which a great divergence of opinion exists. From very careful observations conducted over a number of years and dealing with thousands of tons of coal, I feel inclined to assert that the heat requirements are very much smaller than we have been led to believe in the past. For instance, when distilling bituminous coal of a younger formation, containing from 12 to 13 per cent O_2, we have efficiently distilled this by employing a gas volume of not more than 1 to 1.2 cubic meters per kilogram coal. This gas, with a temperature drop of from 650° to 200°C., only gives up 135 kgm. calories per cubic meter at N.T.P. volume basis. This quantity of heat also covered the radiation and convection losses from the retort. Considering the heat carried away by the solid residue, leaving the system at 450° to 500°C., and the evaporation and superheating of from 5 to 6 per cent free moisture, there is a deficiency of kilogram calories which at first glance renders the heat balance nonsensical. The extra heat can, in my opinion, be supplied only by the exothermic reaction in the coal substance itself, commencing, as I have shown, at temperatures as low as 200° to 250°C., resulting in the formation of CO_2 and combined H_2O. I shall not here attempt to assume what that heat provided through these reactions may be. Nobody knows how the oxygen is combined in the coal substance, but what I suggest is that once the coal substance is heated to 200° to 250° and in some cases 300°C. by the heating gas or by conduction, as in the case of externally heated retorts, the exothermic reactions come into play and carry on the good work to finality. I will admit the boldness of this assertion but it is, it seems to me, the only plausible explanation.

It will be seen that the volume of gas required to carry the heat to distill bituminous coal is very much less than that conducive to good oil. We find that about 2 cubic meters represent the happy mean and corresponds, at a gas producer efficiency of 80 per cent and a combustion chamber efficiency of 85 per cent, to about 300 to 310 kgm. calories per kilogram coal.

Taking raw coal as having a heating value of 6,700 kgm. calories per kilogram = 12,000 B.t.u. per pound, the fuel requirements would, therefore, be 4.6 per cent by weight of the raw coal (theoretical). Taking 7 cubic meters per kilogram coal, we have under the same conditions as above 16 per cent by weight of fuel.

The difference in the oil quality does not in my opinion justify the extra fuel expenditure.

While on the subject of fuel and thermal balances, does it not strike anyone working out a thermal balance between heating value of raw coal entering the retort and the sum of heating values in resultant coke, oil, gas and ammonia, that however careful one is in computing the figures, there is always a loss unaccounted for of from 5 to 10 per cent and even higher of the heating value of the original coal. I believe that this loss in heat is that evolved by the exothermic reactions of the coal substance and is the energy that effects the carbonization and that the fuel we put into the system only starts the operation. We are now carrying out further work on this highly interesting subject, which I hope to make public shortly.

It has been observed on numerous occasions that the younger the coal to be distilled the greater the so-called unaccountable thermal loss is in the heat balance between latent heat units put in and latent heat units recovered. This seems to coincide with the higher exothermic properties exhibited by such fuel during distillation.

Another reason against the use of a very large volume of gas is the cost of power consumed in circulating this large volume and the difficulties in providing adequate condensing plant to recover all the lighter oils.

It will be clear that the greater volume of gas meant a proportionately greater gas velocity through the retort, the area of free suction or gas passage being the same in each case, hence the gas speeds were $3\frac{1}{2}$ times greater. It stands to reason that by diminishing the sectional area of the gas space the possibility of obtaining the same gas velocity with 2 cubic meters gas per kilogram coal as with 7 cubic meters gas exists, and since more than sufficient heat is carried by the lesser gas volume, the rational development would go in that direction; that is to say, instead of employing a filling degree of 20 per cent and free space of 80 per cent, 40 per cent free space and 60 per cent filled space should be aimed at. Care must, however, be taken that the coal under treatment does not act as a Pelouze or impact scrubber for the oil vapors in the colder parts of the retort, but, again, the outlet temperature of the gas should always be well above the dew point of the heaviest fractions.

Employing 2 cubic meters gas per kilogram coal, no troubles are experienced in recovering 95 per cent or more of the total oil evolved. It will be noted that the oil we obtain is considerably richer in the

heavier viscous oils than that produced by externally heated retorts and correspondingly poorer in light oil and spirit fractions. This is, of course, of great assistance when scrubbing a large volume of gas containing a relatively small concentration of oil. It will be understood that when little spirit is formed, the losses cannot be great. The mechanism of the production of lighter oils by the cracking up of the primary heavy oil has only been very imperfectly understood and hence the objections raised in different quarters to the employment of distillation with internal heat.

CONDENSING OF OIL AND COOLING OF GASES

In the century or more in which gas has been condensed very few innovations of a radical nature have taken place. In olden days, and still today, when the gas leaves the retort it passes through air cooled condensers, then water tube condensers in which the temperature of the gas is reduced well below the dew point of the oils and tars, so that these are in globular form and can be extracted in a Pelouze extractor or in a centrifugal washer with oil or tar sprays. The results of these condensing operations have been to produce a crude tar or oil in which all the various fractions were indiscriminately mixed together with the exception of the very lightest motor spirits and benzols—these have to be obtained by washing the gas in separate scrubbers.

One of the first men to begin to think seriously of the condensing question was Dr. Walther Feld. He reasoned that pitch, as such, did not come over from the coal but was formed by the thermal decomposition of the tars when these were distilled and fractionated, and if the condensation could be done in stages, under very careful temperature control, the possibility might exist of eliminating the greater part of pitch and, therefore, produce a tar or oil much richer in oil fractions than before.

Walther Feld was a quarter of a century before his time and although his work and theories will always serve as a shining example for others to follow, times were not ripe for him.

Another man who has done work of real value is Dr. Scheithauer. He realized that slow condensation at the critical temperatures in which the oil and tar vapors leave the retort had to be taken into consideration, and I remember some years ago a discussion with him at one of the brown coal distillation plants in Germany, which he

controlled, and his clear elucidation of why he considered slow condensation to start with essential for brown coal oils.

The next step in condensing practice was also initiated in Germany, and took the form of cooling the gas down to a temperature which was some degrees higher than the dew point of the water vapor present in the gases; that is to say, temperatures ranging between 80° to 90°C. This cooling was done in tubular condensers or by the direct injection of a small amount of cooling water into the gas so that full use could be made of the latent heat of steam formation. The gas passed through centrifugal machines on the disintegrator principle, where a large quantity of tar or oil at the above temperatures was injected and atomized with the gas absorbing the oils and afterwards being drained away or separated out by the centrifugal action. In this way it was possible to obtain nearly all the oil or tar in the gas and this operation was followed by rapid condensing of the gas, either by directly injected cooling water or tubular condensers.

The oil obtained had only from 2 to 3 per cent of water present and consequently the emulsion troubles were successfully overcome.

Still, we had only an indiscriminate mixture as before; namely, all the various fractions put together in one single tank.

Undoubtedly, Walther Feld's procedure was the more correct, scientifically speaking, but he was up against the rather high oil percentage in the gas, so that any slight drop in temperature of the gas would at once, and fatally, influence the dew point of the oils and the fractional condensation would not take place.

Shortly after the Bituminous Congress in Pittsburgh in 1926, and during my stay in the United States, I met Colonel Wagner, chief engineer of the Bartlett Hayward Engineering Company, and during my stay with him we thoroughly discussed Walther Feld's work and it appeared that our method of coal distillation was of such a nature that Walther Feld's old ideas could be applied. We had a very big volume of gas—three to five times or more than that of the ordinary gas works and coke oven processes, consequently the dew point of the oils would not require the same attention and the drop of temperature of some few degrees would not influence the state of the oils or tar vapors in the gas.

Colonel Wagner informed me of his son, who is in England and working on these lines, and attempting to apply fractional condensation to oils—natural well oils—by vaporizing these with steam.

The oils obtained by this process were very excellent but the cost

of vaporizing the oils and maintaining them in vapor form by steam was such that the process could not be economically operated.

On my return to England my company at once obtained the services of H. W. Wagner and ordered an experimental plant to operate in conjunction with our test retort at our station, which was designed on the Feld principle but embodying a new type of washer, specially constructed by us, which in efficiency and cheapness should be superior to the ordinary centrifugal washers employed by Feld.

Here we have all conditions in our favor. We have a large volume of gas which we can maintain at any desired temperature so that the dew point of the oils can be lowered to a reasonable temperature and the oils still remain in vapor form.

The plant consists of four centrifugal washers in series. The first one is operated at such temperatures that only the pitchy matters can be separated, if any such should be found in the crude oil, together with any possible dust or solid matters carried over. From this washer the gas passes through a set of Pelouze plates and straight into the second washer, where the gas is washed with the highest boiling fractions of crude oil. The lubricating fractions are here removed. The middle oils are removed in washer No. 3 and before the gas passes into the last washer it is cooled down to normal temperatures and in the final washer the usual process of removing the light oils and spirits is carried out. We have done a considerable amount of work on this new plant and I am glad to be able to inform you that the indications are distinctly promising, but, of course, we have to learn a good bit more about the mechanism of condensation itself.

We find that the dew point of the heavy oil fractions in our oil and gas mixture is about 200°C. and the gas will leave our retort at about 250°C.

The temperature of the gas must be reduced to 200°C. slowly and this is what Dr. Scheithauer considered advisable in his brown coal plant which I mentioned above. It seems that when the oils leave the retorts they are in an unstable chemical equilibrium and time must be given them to find themselves, so to speak. If shock cooling or rapid cooling is adopted, the quality of the oil is not nearly as good; if, however, a certain time is allowed to elapse during the preliminary cooling down, the quality of the oils is very much improved.

I must here remark that very little is known about the complex

high molecular weight bodies we find in the oil, and in a preliminary condenser we must apply the rule of thumb at present at any rate.

I cannot give any satisfactory explanation of the necessity for this initial slow cooling, barring the above and the fact that by slow cooling the oils appear to be superior.

If the oils are still in their vapor phase, and at temperatures below, say, 100° to 120°C., rapid cooling does not seem to have any influence. We fully believe that this new and rational method of condensing, based on Walther Feld's old ideas and coupled with the progress in distillation, will be of great value, but we have not yet completed our work. However, as I said before, the indications are very promising.

Naturally there is no reason why several more washers should not be put in series so as to obtain as many different fractions as possible, and it is clear that the oil refining and distillation, whieh subsequently takes place, is very much facilitated and there is never any trouble with the emulsions, priming, etc., and, in fact, the condensing plants act as the first run stills in ordinary distillation of oil.

The condensing plants are also considerably cheaper and can be controlled and worked under far more stringent conditions to yield uniform products than can be done by the other methods of condensation.

We have observed indications that the total quantity of pitch by the proper fractional condensation will be very much reduced, although I must say that the amount of pitch we find in our erude oil is considerably less than that found in oil obtained by externally heated processes or by internally heated processes where the oil has a chance of being cracked up or superheated.

Theoretieally speaking the quantity of piteh should by proper distillation and fractional condensation be reduced to practically zero and there is no doubt that pitch, during the oil distillation, subsequently very much accelerates the cracking up of the various oil fractions and that an oil once cracked is more liable to crack on subsequent treatment than oil which has been very slightly cracked or not cracked at all. At any rate the ideal we have to work towards is to obtain the oils in the state in which they are set free from the coal substance so that we can talk about primary products.

An interesting observation we have made is that a greater portion of the solid matters, generally referred to as dust, in oils obtained from coal is not merely dust from the find grinding of coal, or dust

present as such, but mostly due to the fact that oils have been overheated and free carbon produced, and we find that by altering the retorting temperature and the operation of the cyclone we can, at will, produce an oil high in duct or low in duct from the same material.

It is, therefore, clear why high temperature tars obtained from coke oven and gas works retorts are so very high in benzol insoluble matters; in fact, we believe it is almost possible to predict the temperature to which an oil has been subjected when distilled from coal and the distillation conditions merely by the amount of benzol insoluble matters in the oil.

It will here be seen that a very wide field has been opened up for future research, but although very much work still remains to be done, the ultimate gain is great and, incidentally, the abstruse subject of the constitution of coal will be somewhat further elucidated.

FINAL REMARKS

In selecting a few specific points for discussion among the multitude of interesting things confronting one on the subject of coal, it is with considerable diffidence I have chosen the above.

I realize fully that we have only, so to speak, scratched the surface, but I believe that the points I raise present features sufficiently interesting for others to carry on along the lines indicated. We shall continue, but the more work done in different places along independent lines on the same subject, the greater the chances are of some new fact being elucidated, helping and assisting in throwing light on something which was in darkness before. I believe that, although we still say that we know very little about coal, that applies just as much scientifically as to economic utilization. We are on the eve of great things and any little discovery, however trivial it may seem to be at a first glance, is of importance. We simply cannot afford to keep scientific observations, once they have been verified, to ourselves. The whole of the fabric in our civilization is so interwoven with interdepending problems, that it is our duty to come out in the open and explain frankly. I admit that the propensities of co-ordinated science in the future almost frighten me with the vast possibilities they possess. Whether this can be successfully done without a certain amount of private and official jealousy, I shall not venture to predict. Still progress goes on. Human nature is such that hindrances only make the desire keener.

I said above that it was with diffidence I selected the oily constituents of coal; I might equally well have selected the gaseous or solid products. The groups with which I have the honor to be associated carry out work along these lines as well. We believe in the possibilities of town gas produced in a new way, with the recovery of oil products, this gas to be sent by long distance transmission to places where gas is dear and scarce. Personally I took this matter up for discussion two or three years ago (*Gas Journal*, February 10, 1926). I think there is room for improvement. Well, people may say, there is 170 million sterling invested in gas works in Great Britain, and they are all paying their way. Yes, of course they are; they are in a favored position, they are granted charters and monopolies and have powers to levy a higher price on the gas they sell in times of need. The consumer has to pay. Low temperature distillation is in a different category altogether; it has to face competition in the open market. One might for comparison's sake say that there is the same relation as between the wages paid to labor in sheltered industries—postmen and municipal employees—and those paid to the miners and steelworkers who have to rely on what their labors and produce may bring in in competition with those in foreign countries. Present high temperature gas works practice has about reached its climax in efficiency, and if something more is wanted by the march of time, a radical change has to take place. This, long distance gas supply from centers conveniently situated, will bring about: the writing is on the wall.

So it is with the utilization of the solid fuel. We must learn to separate all the more valuable or more profitably employable constituents and only consume by fire those parts which can find no more profitable use. The tendencies here go in the direction of rendering the solid material subject to the same handling facilities as a fluid, namely, by powdering or conversion to an industrial gas, be it producer gas, water gas, or by reduction of water, to hydrogen. Again new uses are found for this old product reappearing in a new form, and so it goes on *ad infinitum*.

We must treat coal as a base which is separated into three main raw products of the most suitable character, namely, gas-oil-solid, by the most efficient and economical method, these three raw products again forming the starting point for the various and multitudinous products our civilization demands.

Conclusions

The exothermic reactions of coal at lower temperatures have been discussed in conjunction with the heat requirements for the actual distillation of coal.

It has been shown that the neutral petrol-soluble oils obtained from bituminous coal and brown coals are identical, within the experimental errors.

It has also been shown that the oil given off by bituminous coal from the first stages of distillation is practically identical with the oil given off during the subsequent and final stages of distillation, within the experimental errors.

The importance of the rapid removal of distillation products fro the hot zones is discussed and experimental data appended.

The possibilities of fractional condensation are discussed

LOW TEMPERATURE DISTILLATION, THE BRITISH COAL INDUSTRY AND OIL SUPPLIES

By R. H. Crozier

Manager, Mineral Oils Extraction, Ltd., London

Read by William E. Mott, Director of the College of Engineering, Carnegie Institute of Technology

The problem of, perhaps, the greatest social and industrial importance facing the British nation today and the one which will have the most vital and far-reaching effect on our national prosperity, is that involved in the low temperature distillation of our coal resources. With the possible exception of the agricultural industry, the coal deposits of Great Britain constitute the greatest factor of our national potential wealth. At present, under the wasteful methods of coal consumption prevailing in this country, only a small fraction of this wealth is being realized. The maximum realization must attend a more accurate economic classification of the various coals, the diversion of each class to the purpose for which it is most suited and pretreatment by low and high temperature processes. In such a development, low temperature distillation is destined to play a most important part.

The low temperature industry by virtue of its bearing on questions of power production, coal output and oil supplies, is essentially a key industry and the measure of success which attends the various efforts now being made to establish low temperature distillation as a profitable commercial proposition, will be reflected by an increased prosperity in practically every other industry in the country.

For many years, British coals held a place of supremacy as the world's greatest individual source of power, and on this foundation, our industrial prosperity has been largely based. With the advent of cheap petroleum fuel, the development of the internal combustion engine for ship propulsion, the harnessing of water power for the production of cheap electrical energy and the exploitation of foreign coal deposits on an ever increasing scale, the supremacy of British coal as a major source of power has been severely challenged and the coal industry is now suffering from the combined effects of competition from several directions. This competition together with the increasing cost of winning coal from the older collieries, has resulted

in a state of depression, rapidly becoming chronic, from which it is difficult to see any prospect of adequate relief, except through the conversion of coal to new uses and the recovery of various products the gross value of which will be in excess of the present value of the raw material.

The Royal Commission on the coal industry in 1925, reported the estimated reserves of coal in seams at mineable depth, at 197,000 million tons. Based on its period of potential life, therefore, the industry may be said, in the hundred years of its present development, to have passed through a stage of infancy, during which it has been fostered by favorable economic conditions and the efforts now being made at reorganization on rational lines, may be regarded as healthy signs that a dawning intelligence is being exerted to meet the more strenuously competitive conditions of maturity. The various schemes on foot such as the amalgamation of coal mines, reorganization in administration and coöperation in marketing, while tending, doubtless, to improve the situation, do not strike directly at the root of the trouble. The writer is of the opinion that the day of raw coal as a predominant factor in economic power production is passing and that in the future, the coal industry will depend more and more for its profits upon the value of the products extracted by low temperature methods of treatment, whilst cheap semi-coke, burned efficiently in pulverized form, will be recognized as the economic fuel for power production in stationary, locomotive, or marine type boilers, or for the production of electrical energy through the medium of suction gas generators.

Let us now examine some of the considerations influencing the problems from the point of view of low temperature processes in this country. There is mined in Great Britain, approximately 250 million tons of coal each year. Although the bulk of this coal is classified as bituminous coal, it consists of materials widely different in their chemical structure and composition and, more particularly, vastly differing in their behavior under heat treatment. Many coals such as those from Durham, Kent, certain seams in Northumberland, Yorkshire, Wales, etc., pass through a phase of liquefication, and the separate pieces coalesce completely on heat treatment, others exhibit only a slight tendency to coalesce, whilst in many, the coalescing tendency is completely absent. We have, therefore, in considering the question of distillation, extreme differences in technical behavior to provide for, and to refer, as is commonly the case, to *the* low

temperature process for coal treatment, is about as illogical and misleading as it would be to suggest that one metallurgical process would be equally suitable for the treatment of all ores.

Coalescing coals, on account of the inherent difficulty of dealing with hot, semi-plastic and sticky masses under commercial conditions, must obviously, require more costly and mechanically complicated retorts for their treatment than those coals which, by virtue of their non-coalescing character, rill freely by gravity under normal retorting conditions. Retorts designed for the low temperature distillation of highly caking coals will, therefore, be of small individual capacity, high initial cost and expensive to operate. In addition, the semi-coke produced from the treatment of coalescing coals is light, friable, and porous in character. Consequently it breaks down in handling and transport, burns away rapidly and is generally unsatisfactory as a domestic fuel in comparison with the dense, robust coke produced from the treatment of non-coalescing or "free-retorting" coals, which coals, further, yield oils equal in quality and quantity to the oils yielded by the more difficultly treated and usually more costly, caking coals.

We find, however, that the quality of fusibility which makes coal undesirable for low temperature distillation is just that quality which is practically essential for high temperature carbonization processes, in which a dense coke is produced by the pressure in the retort, resulting from the restricted expansion of the coal in a stationary charge. Consequently, by a natural process of industrial selection, our coals of high caking character, find preferential markets in the coke-oven and gas making industries, both in this country and abroad, while the "free-retorting" non-caking coals constitute the bulk of 147,000,000 tons, that, according to the report of the Royal Commission, are at present burned wastefully every year in the raw state. It is the smoke from this coal, mostly consumed in open fires, which causes such incalculable inconvenience, loss and distress to the community.

Obviously then, the sphere offering the greatest financial, industrial, and communal advantages for the development of the low temperature distillation industry in Great Britain, lies in the treatment of simple "free-retorting" coals, the present mode of consumption of which, is little short of economic scandal.

The writer estimates that at least 80,000,000 tons of the 147,000,000 tons of coal consumed annually for industrial and domestic purposes,

are of a character suitable for treatment in the simplest form of gravity flow retort. This estimate is based upon an intimate practical study, extending over several years, of the relationship of low temperature distillation to the British coal problem.

During this time, many hundreds of typical samples have been examined and tested and numerous bulk consignments of coals treated in a commercial scale retort under continuous working conditions. The yield of oil recoverable from the distillation of coals of the non-coalescing character referred to, varies widely, from as low as 10 gallons per ton, to as high as 40 gallons per ton. The average yield may be placed in the vicinity of 22 gallons per ton, but there is undoubtedly a very large tonnage of coal at present mined, from which a yield of over 30 gallons may be recovered in commercial retorting. The major portion of the 80,000,000 tons, is at present burnt for domestic purposes in open household fires. Its consumption in a raw state is not only a direct economic loss to the community and the cause of an enormous indirect expense, owing to the deteriorating effect on property of a smoke-laden atmosphere, but is also through the atmospheric pollution created, a serious menance to the health and physical development of the population of our cities. The distillation of this coal is, therefore, desirable for many indirect reasons.

Apart from such considerations, however, the pretreatment of this coal would yield over 7,000,000 tons of low temperature oil per annum, from which can be extracted a considerable portion of the liquid fuels at present imported into Great Britain from foreign sources. The home production of such oils must, of course, have an important bearing on the national balance of trade and it is largely the recognition of this fact that has induced the British Government to impose the present tax of 4d. per gallon on imported motor spirits.

The most cursory examination of the problem from the point of view of establishing the industry on a scale commensurate with the nations need, indicates clearly, that the retorts for the distillation of the coal must be of large unit capacity, simple in construction, fool-proof in operation, of low capital and operating cost, and capable of working continuously from one year's end to another. The late Sir George Bielby in reviewing the subject of low temperature distillation in a report on the work of the Fuel Research Department, estimated that the capitalization involved in establishing the industry in England, would be approximately £1 per ton annual throughput.

Since the date of Bielby's report, however, much progress has been made in the art of coal distillation and at least one process fulfilling the considerations outlined above has been developed, which will permit the industry to be established on a capitalization basis of considerably less than £1 per ton annual throughput.

By way of comparison with kindred industries, it may be mentioned that the coke oven industry of this country possesses over one hundred and fifty plants, and carbonizes approximately 19 million tons of coal per annum. The capital engaged in this industry is in the neighborhood of £40,000,000 or over £2 per ton annual throughput. Again, in the British gas industry which deals with over 18 million tons per annum, there is now engaged a capital of £160,000,000 equivalent to nearly £9 per ton annual throughput. It is evident, therefore, that in comparison to the gas and coke oven industries, the capital required to establish the new coal distillation industry would be comparatively small.

It has frequently been suggested that the chief obstacle to the economic establishment of the industry in Great Britain is the disposal of the semi-coke. In dealing with bituminous coals, this coke would amount to between 60 and 75 per cent of the coal treated. It is an excellent fuel, usually of equal or of slightly higher calorific value than the original coal and in many ways superior to the hard coke produced by the gas industry. It ignites and burns readily in the ordinary domestic grate, with a clear, cheerful, smokeless fire. As a boiler fuel it is superior in heating efficiency, to raw coal, especially for tubular boilers, as there is no soot formed to clog the tubes or flues and a much steadier fire can be maintained. It also offers many advantages as a pulverized fuel and, as it burns with a short-length flame, with a suitable burner, its use in pulverized form may be adapted to power plants, without expensive reconstruction of existing boiler installations. The semi-coke would also be particularly valuable as a gas producer fuel, and for this purpose may be used advantageously as a substitute for anthracite.

Many markets, therefore, already exist where the semi-coke may be disposed of as a substitute for raw coal or gas coke, and provided—as would appear to be the case—it can be sold at prices competitive with these materials, then its disposal would not be difficult, but turns rather on the matter of educating the public to an appreciation of its superior value. In this connection the tightening of local regulations regarding smoke abatement and the introduction of

legislation to prohibit the production of smoke from domestic and other fires in our cities, would ensure the adoption of a new fuel. Apart from such considerations, however, the merits of the fuel itself must lead to its popularity.

Semi-coke in pulverized form offers great possibilities as a substitute for fuel oil. It can be pumped, piped, syphoned and injected and dealt with in practically every respect as a liquid. Probably the greatest obstacles hindering the adoption of pulverized coal for marine purposes are the liability of coal dust explosions occurring in the bunkers, and the large firebox space required for combustion. In dealing with pulverized semi-coke the possibility of explosion is practically non-existent, while it has been determined, that on account of its short length flame, the combustion space required for burning the semi-coke is only 60 to 65 per cent of the space required for the combustion of pulverized coal.

It is not difficult to visualize the bunkering of ships, in the near future, with pulverized semi-coke, prepared on land and pumped to the ship tanks, in much the same manner that vessels are at present bunkered with liquid fuel.

Turning now to the larger question of Empire oil supplies. Vast sums of money have been expended in prospecting the most likely places in the Empire, in efforts to discover commercial oil pools. So far the results from this expenditure have been largely negative and there now seems little likelihood of adequate supplies of natural oil being obtained from sources entirely within our territories. On the other hand our consumption is increasing rapidly and it is probable that while our requirements will be considerably greater within the next few years, the sources from which supplies are at present drawn, may, through depletion of the wells, diversion of the products to other markets, or through international complications, no longer be available to contribute to our necessities.

While there may, perhaps, be little justification for the many pessimistic prophecies regarding an imminent exhaustion of the world's natural oil deposits, it is quite obvious that the annual progressive increase in oil consumption is more certain to persist than is a continuation of an annual increase of production. The result must inevitably be a general oil shortage, the effects of which would be felt with particular severity throughout the Empire, owing to the wide geographical dispersion of its Dominions and our unfavorable situation with regard to natural oil reserves. Much has already been

written on this subject and it is, perhaps, unnecessary to dwell on the disastrous effect of a serious oil shortage would have on the development of the Empire, the very security of which is largely based on an oil-driven sea power.

The following statistics regarding the importation of petroleum products into Great Britain and several British territories, emphasize the need for an Empire oil supply.

	Petroleum Imports	£
Great Britain	14,324,217	77,009,351
Canada	3,882,937	10,813,643
Australia	1,136,041	10,112,000
New Zealand	378,041	3,707,371
South Africa	255,777	2,652,180
India	918,801	6,898,095
Nigeria	27,598	422,812
British Malaya	904,024	12,617,468

All the above countries have resources of coal, lignite and oil-shales, from which oil may be obtained by a simple process of distillation. These resources may be summarized briefly as follows:

Australia possesses in the torbanite deposits of New South Wales, some of the richest oil-yielding material known. A consignment of this torbanite treated by the process known by the writer's name, yielded 163 gallons per ton. The oil is of excellent character, which on refining gave products of the highest quality. It is estimated that there are 44,000,000 tons of torbanite, which will yield in the vicinity of 100 gallons of oil per ton, in the various deposits known in New South Wales. The tasmanite deposits of Northern Tasmania also constitute a potential Australian oil supply of considerable magnitude. These deposits were estimated some time ago, to contain over 50,000,000 tons of material which would yield approximately 40 gallons of oil per ton. Recent further discoveries, however, indicate that the reserves are now much in excess of the figure mentioned. In Queensland and Western Australia, oil-shales of good quality are known to exist. These deposits, however, have not yet received much attention and their full extent has not yet been determined. The enormous brown coal deposits of Victoria and Southern Australia are too well known to need special reference. It may be interesting to note, however, that the wet coal (45 per cent moisture) yields 11.3 gallons of paraffin base oil per ton.

New Zealand. The sub-bituminous coal deposits of New Zealand

are estimated to be in excess of 500,000,000 tons. These coals yield variously from 12 to 35 gallons of oil per ton. The deposits in most cases are of good mining width, inexpensive to work and the coal offers no technical difficulty whatever in treatment. New Zealand also possesses an oil-shale deposit of considerable importance at Orepuki in the South Island. This shale yields 45 gallons of oil per ton. An effort was made some years ago to work this deposit, but owing, it is understood, to the unsuitable type of retorts installed, the enterprise failed commercially.

South Africa. The bituminous coals of South Africa of which a large variety have been tested, by the writer, yield oils of average quality and quantity. The deposits of the Union are estimated to contain 250,000 million tons and constitute a potential oil reserve, the importance of which as a factor in the industrial development of the Union it is difficult to overestimate. In addition to her coal deposits, however, several deposits of oil-shale are known to exist in South Africa. Of these perhaps the Ermelo torbanite deposit, situated about 130 miles from Johannesburg is of the most immediate importance. The torbanite exists as a composite seam about 11 inches thick, associated with about 3 feet 6 inches of bituminous coal of good household quality. The torbanite seam is somewhat lenticular and irregular in character and the reserve is variously estimated at from 9,000,000 tons to 11,000,000 tons. The material is simple to treat and yields over 100 gallons of oil per ton. The torbanite can be mined and treated cheaply, without difficulty, and on account of the favorable geographical position in relation to the industrial center of Johannesburg, the deposit possesses advantage over others which should make its development commercially attractive.

Nigeria. Nigeria is a country of great natural wealth and rapid progress is being made with its development. The country possesses two coal deposits of great interest and importance. Of these the black sub-bituminous deposit is being developed by the Government at the Udi mine. This coal is being used exclusively on the Nigerian railways and is finding an export market in adjacent British and French territories. The coal, on account of its high volatile content, however, cannot be regarded as a first class fuel for steam-raising purposes and its consumption requires some modification of the normal type of fire-box. It is, however, particularly suitable for distillation and yields over 30 gallons of oil per ton. The semi-coke

residue is a fuel of much higher calorific value than the original coal and is equivalent to the highest grade steam coal in heating efficiency.

In addition to the Udi sub-bituminous deposit, there exists an enormous deposit of brown coal, the series, it is stated "can be mapped continuously over a distance of 400 miles." This brown coal is superior in quality to any other which the writer has examined. Many samples have been tested, some of which have yielded as high as 57 gallons of oil per ton. The coal beds underlie gently and vary from 12 to 23 feet in thickness. Much of the deposit may be mined by open-cut-working, and with the labor available, the cost of operation, both for the mining and retorting would be low.

Canada. The resources of sub-bituminous lignite in Canada appear to be practically inexhaustible. The writer's experience with these coals, however, is that the oil yielded on distillation is somewhat low and so far, none of the coals which he has tested have yielded more than 10 gallons per ton. There is little doubt, however, that a systematic examination of the numerous beds available will reveal coals of high oil yielding character. Owing to the low price at which United States petroleum products are available in Canada, the question of coal distillation regarded only from the point of view of oil production, would not appear commercially attractive. There is, however, the more important question of up-grading the coal and the production of a high grade fuel to supply the industrial and railway requirements of the Western provinces. With this aspect in view, the question of coal distillation in Canada is one of considerable national importance.

In additon to her coal deposits, Canada has enormous resources of oil-yielding materials in the bituminous sands of Alberta and the oil-shale deposits of New Brunswick. Both these materials, however, present peculiar technical difficulties in treatment, which must necessarily complicate and add to the cost of extracting the oil.

Special reference should be made to the torbanite deposits of Pictou, Nova Scotia. These deposits contain considerable reserves in seams which yield from 30 to 60 gallons of oil per ton. The Nova Scotia torbanite is simple to treat and the oil produced is clean and may be refined without difficulty by normal methods. Their geographical position gives to these deposits a strategical importance as a possible source of oil for naval purposes in the Northern Atlantic.

India. Domestic conditions peculiar to India, give to the question of coal distillation in this country, a national and economic impor-

tance which is not generally recognized. Practically the whole of the cooking of the country is done over small open fires, fed either with charcoal or dried cow-dung as fuel. With the increasing cost of charcoal resulting from the clearing and depletion of forests adjacent to the centers of population, more and more cow-dung is being used for cooking purposes. Consequently the soil in agricultural areas is being impoverished through being deprived of the humus and nitrogen producing bacteria which would normally be returned to the ground were the animal droppings used for manurial purposes. This condition of affairs is the cause of much concern to the Government and the local authorities of the agricultural districts. The fumes produced from the cow-dung fuel are also very objectionable and the character of the acrid, miasmic fog, produced from hundreds of thousands of cooking fires, which settles in the narrow streets of the native quarters of a city like Calcutta during the monsoon season is neither pleasant to imagine nor experience, and the Calcutta statistics of deaths from pulmonary diseases reflects the prevalence or absence of fog with remarkable fidelity.

India possesses good oil producing coals, simple to treat, from which could be produced a cheap smokeless fuel to substitute the domestic fuels at present universally used throughout the country. The establishment of the low temperature industry in India, therefore, would, apart from the commercial aspect, be of material indirect benefit to the country and community and might justly claim the active interest and support of the Government.

In Burma the conditions are different and practically all the coal used in the country is imported from India or South Africa. The province possesses, however, deposits of sub-bituminous coals of considerable extent. Of these the deposits of Mergui (Lower Burma) and Namma in the Northern Shan States and Kalewa on the Chindwin River are of major importance. The Namma and Mergui coals are both poor oil producers and yield respectively only 5 and 10 gallons to the ton. The Kalewa coal, however, is of superior quality and on distillation yields over 17 gallons of oil per ton and leaves a semi-coke residue of high calorific value which in briquetted or pulverized form would be an excellent railway or industrial fuel.

Burma also possesses an important oil reserve in the tertiary shale deposits of the Thaungyin valley near the Siamese border. This deposit is of considerable extent and is remarkable for its regularity and freedom from faults. In a half square mile of the deposit, which

was bored under the writer's supervision, 13½ million tons of high-grade shale was proved to exist. The shale exists in several seams in a shallow lake basin. The major seam has an average width of 6 feet and yields 45 gallons of an oil of exceptionally high paraffin wax content, per ton.

British Malaya and the Straits Settlements. Both in Malaya and on the Island of Labuan in the Straits Settlements, there exist important deposits of sub-bituminous coal which yield from 27 to 29 gallons of oil per ton. The Labuan mine is not at present being worked, but the Malayan deposit is being mined by the Malayan Colliery Company and supplies practically the whole of the coal consumed for railway and industrial purposes in the Federated States. Mention should also be made to the deposit at Enggor in Malaya. The Enggor coal, however, is of poorer quality than that mined by the Malayan Collieries and yields only 5 to 6 gallons of oil per ton.

CONCLUSION

The United States is at present producing over 75 per cent of the world's petroleum output, and so long as this production can be maintained, there is little reason to fear any serious British deficiency. Some two years ago, however, the United States Oil Conservation Board drew attention to the fact that at the present rate of production, the known reserves of petroleum could not be relied upon for many years. The statistics already quoted in reference to the petroleum importation into some of the more important British countries, indicate that our present consumption is over 130 million barrels per year. Of this quantity some 70 per cent is drawn from foreign sources; the United States being our most important source of supply.

It is evident therefore that any serious decrease in the United States oil production would be quickly reflected by a shortage and increased price for oil products in British countries.

It is only necessary to study the statistical history of the Californian fields to realize how quickly a serious deficiency of supply may develop and that a few months unsuccessful "wild-catting" corresponding with the exhaustion of present flush fields, may quickly bring about a drop of 50 per cent in production.

We have within British territories, ample supplies of raw materials from which the bulk of our oil requirements may be extracted by

distillation. The average yield from such materials would be considerably under one barrel of oil per ton. It is evident, therefore, that to make good any considerable percentage of our present consumption would involve the treatment of millions of tons of coals or oil-shales every year and the creation of a new industry of unprecedented magnitude, the development of which must be undertaken without delay if we are to be in a position to meet the inevitable oil shortage when it occurs.

DISCUSSION

A. C. KUNBERGER (United Gas Improvement Company, Philadelphia, Pa.): I would like to ask Mr. Allen whether he can give us the gas yield, tar yield, coal yield, and likewise the investment cost per ton with this process which you have so wonderfully described to us.

W. H. ALLEN: I can give you the yields obtained in our small assay furnace, which are probably considerably more accurate than the results obtained at Philo under conditions of apparatus development and constantly changing mechanical features.

Judging from our pilot furnace tests I would say that the coke yield on the dry basis should be about 72 to 73 per cent from coals which will average, say, 36 per cent volatile. We obtained gas yields all the way from 1,800 to 2,600 cubic feet per ton. The gas yield by this process is rather low, because there is almost a complete absence of cracking.

The tar yields in all of our tests at Twin Branch averaged better than 30 gallons per ton. In the large equipment at Philo, as we operated last year, the gas yield probably averaged 2,000 cubic feet, and the tar yield was approximately 24 gallons. We were using rather lower volatile coals than in the Indiana tests. The coke yield was just about what you would calculate.

As to the cost of equipment for a commercial plant, would say that we do not consider this Philo equipment really a commercial unit. Undoubtedly the diameter of the machine is great enough, but we are not absolutely sure what the best length would be; and I can, therefore, only estimate the cost of the plant. From various estimates I should say that the cost of a complete plant for 200 or 300 tons per day—that is a small-sized plant—would be $900 or $1,000 per ton capacity per day. With a larger plant I think the cost could be reduced.

T. G. WEBER (Central Union Gas Company, New York, N. Y.): Can Mr. Allen tell us what percentage of coarse material and fine material he got in the coke in this process?

MR. ALLEN: We had quite a variation in sizes and found it took a little time to learn how best to treat each kind of coal. I suppose this is on account of the differences in melting points and a good many other factors. As a rule, about 20 per cent would pass through a $\frac{1}{4}$-inch opening.

MR. WEBER: That is from the West Virginia coals?

MR. ALLEN: Yes, that is from the West Virginia coals, and some of the Ohio coals which were successfully used under certain conditions.

The commercial product has been as high as 90 per cent, but I should say 80 per cent would be a fair average.

A. T. CHILD (Polytechnic Institute, Terre Haute, Indiana): I would like to clear up a point about construction, if Mr. Allen will tell me if at the present time they advocate thermodizing with heating gases in direct contact with the shell, and if they use gases of combustion, and if the thermodizing air is in direct contact with the coal.

MR. ALLEN: Only the heating gases are in the annular chamber.

MR. CHILD: There is no point in thermodizing with gases of combustion in direct contact with the coal?

MR. ALLEN: Not in our work today.

The air was merely passed through the thermodizing rotor, which gave some oxidation. I do not think it requires very much air. But we still believe that the oxidizing has a useful purpose.

MR. CHILD: Have you worked on Indiana coal? Do you know what the lump coke percentage was?

MR. ALLEN: We had about as good success with the coke-forming tendency with Indiana coals as with any others. In fact, they were more universally easy to handle.

F. C. GREENE (Old Ben Coal Corporation, Chicago, Ill.): I saw the product made by Mr. Allen's work, and in very much larger quantities than the samples here. It was interesting to me from the fact that when he got through with his product he was finished. That is an item, I think.

The interesting thing is that you have an excess (in low temperature work) of the plastic medium, in which the fines are usually reincorporated, if that is necessary. Practically all of the easily meltable coals can take up, I would say about 30 per cent, maybe a great deal more, of fine material.

Now I take it, Mr. Allen, that your material, rolling up into balls, of course, has got to be in the plastic, pliable state, and I would like to ask you if you made any effort to re-introduce the degradation product to your retorts to see what your result would be. In other words, could you arrive at a certain maximum of degradation which could always be re-absorbed in your retorts?

MR. ALLEN: We have not attempted that so far, Mr. Greene. We have had it in mind from the very outset, and I am quite confident that with the coal that has marked fusibility, we could take care of at least a large part of our fines by re-introducing them with the coal.

LOW TEMPERATURE DISTILLATION OF HIGH MOISTURE COALS

By F. Seidenschnur

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During past years I have studied, with several collaborators in my department of the State Institute of Brown Coal Research in Freiberg, the low temperature distillation of all kinds of coals which are rich in moisture. We have devoted ourselves chiefly to the German brown coal, in both its amorphous and lumpy forms. The reasons for this study lie in the fact that the State of Saxony itself operates the brown coal mines located in the state territory, and we find that these coals, though rich in moisture, have a higher percentage of bituminous matter than other coal. The prospect of obtaining any particular desired quality of brown coal coke and tar was responsible for the intensive research. Since tars produced from coals with a higher moisture content have often a large amount of paraffins, a transformation of these tars into readily marketable products by simple processes is easily effected.

In view of the great developments in drying and briquetting of brown coal in the last two decades on a purely physical basis and carried out on a large scale, the solution of the above problem seemed relatively simple. We found, however, many difficulties arising as our experiments progressed; their solution has cost much time and work.

It is the purpose of the following discussions to show how these difficulties were overcome, and how a technical solution of the low temperature distillation of coals with a high percentage of moisture on a large scale is possible by the method which I use.

Coals with a high content of moisture, as for instance the German brown coal, the moisture of which varies from 45 to 60 per cent as compared with coal with a moisture content of 5 to 10 per cent, are brittle not only in the amorphous form, but also in the lumpy form. This property of the coal must be considered in the initial processes of the low temperature distillation. Special attention must be given also to the classification according to size and to the treatment of the fine part of coal. The drying process is particularly important and

requires a special treatment. By these necessary processes the technical as well as the economical success of the low temperature distillation is strongly influenced.

The German brown coal briquet industry has been guided until now by the desire to reach a stage of high production without paying attention to the second peculiarity of this coal, that is, its high shrinkage. Coals of either amorphous or lignite structure, with high moisture content, show the properties of a typical colloid. The consistencies of these structures during the removal of the moisture can be preserved only if the shrinkage, which, for instance, in the case of German brown coal, amounts to 40 per cent of the volume, is considered. The modern drying processes used in the preparation of brown coal on a large scale, by means of the well-known steam-heated dryers, do not make any allowances for the shrinkage of the brown coal. This is the same in drying processes using hot gases as transmitters of the heat. The disadvantage is, then, that the brown coal, which is to be dried, crumbles and a considerable part of it escapes in the form of moist dust with the air that is introduced into the drying apparatus for the purpose of removing the moisture from the raw coal. The separation of the dust from the air requires special attention and expense, even if part of it may be used as fuel in pulverized coal firing.

The peculiarities described of the coal with high moisture content and their behavior in the present drying processes in large scale production induced us to adopt a process of handling amorphous and lumpy coals more carefully. I have repeatedly reported the results of these experiments in publications.[1] It was possible to obtain a completely uniform drying of coal; for example, coal of a size between 20 and 35 mm. grain without crumbling the pieces. Like in the ceramic industry, the coal to be dried was first heated thoroughly with hot air saturated with vapor, then the regular process of drying went on by diminishing the content of vapor in the hot air. Balls which had been produced in an egg-shaped press out of moist mine coal with the grains not over 20 mm. in size, showed in this form such a resistance to pressure that they could meet certain mechanical requirements. They maintained their structure like sifted coal if dried to a moisture content of about 15 per cent. In the practical application of the above-mentioned drying process the so-called band

[1] Munnkohle, 1924, 121, 146; *Das Gas und Wasserfach*, 924, F. 28.

dryer or belt conveyor was used. This rotating belt consists of narrow bars arranged at an interval of 2 mm. By means of fans over and under this belt, as shown in Figure 1, the hot gases are continuously forced through this layer of coal and the moisture of the coal is removed to the desired content by exhaust fans. By adding hot gases with a relatively small water content, the gas stream, which is circulating in the dryer can be heated up to the temperature necessary in the different parts of the apparatus.

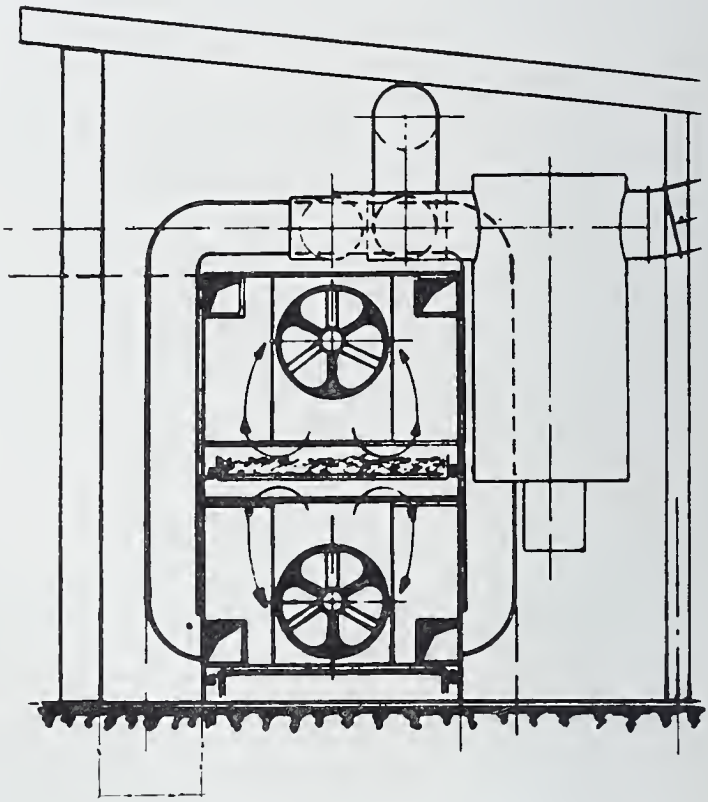


FIG. 1. CONSTRUCTION OF THE BAND DRYER

The dry balls produced on the belt are in every case so firm as to withstand transportation to the shaft where the tar is extracted. The resistance, with which the dry product withstands the wash gas stream during the distillation process, has proved, during our experiments, to be very small; it was approximately equal to a water column of 180 to 200 mm. The experiments, in this case, have been worked on in our trial plant for many weeks with quantities from 5 to 7 tons

per day, based on moist raw coal as received, or as in the distillation shaft having a capacity of 600 to 800 kgm. per square meter.

The relatively small amount of crumbling of these balls made from fine earthy coal during the preparation process described is demonstrated by the grain composition of the coke. Even when fine coal under 10 mm. grain was experimented with, a coarse coke could be obtained containing about 30 per cent of a grain of a size more than 10 mm. and 70 to 80 per cent of a grain of a size of more than 3 mm.

Fig. 2. View of Amorphous Raw Brown Coal and the Coarse-grained Coke Derived from it

Even from the amorphous raw brown coal a coarse grain coke was obtained, as shown in Figures 2, 3 and 4, which does not show any noticeable relationship to the original earthy coal.

In the past year, the first part of a plant for large scale production with a daily output of 100 to 125 tons of raw brown coal, was financed by the Braunschweigischen Kohlenbergwerke, Helmstedt, as an addition to their power plant in Harbke. The plant was constructed by the Flammkok-Gesellschaft M. B. H. Magdeburg. This company

makes use of the methods developed in Freiberg. The results in this industrial plant have confirmed the theories brought out in the Freiberg experiments. The construction of a second plant, which will at first produce 300 tons daily, is being planned by another company and may be completed in a short time.

From the schematic diagram in Figure 5 the manufacturing process of large scale production can be visualized readily. The moist raw brown coal is brought in coal cars. In our special case, the coal comes under 10 mm. grain to the coal bunkers. By means of a con-

FIG. 3. CLOSE VIEW OF COARSE-GRAINED COKE FROM AMORPHOUS BROWN COAL

veyor, this coal is brought to the egg-briquet press. The balls slide automatically without chipping on to the conveyor band of the drying apparatus, so that they may be dried to a moisture content of about 12 per cent. In this state they are conveyed to the distillation shaft where the tar is extracted by wash gases. By means of specially constructed gas-proof sluices the coke, which is cooled by the introduction of gases, is taken out by an elevator to a mixing drum where it is rinsed with water in order that it may be used with a moisture

content of 25 per cent as domestic fuel, or be put through an oxidation process of which I will speak later.

The hot gases used for the dryer and distillation shaft are produced by the combustion of generator gas in an individual combustion chamber. Special care must be taken to prevent the introduction of oxygen to the hot gases used in the distillation processes. The gases extracted from the distillation shaft and from the gas producer, which contains the various distillation products, pass now into a centrifugal washer for the purpose of extracting the tar. The benzine vapors,

Fig. 4. Coarse-grained Coke Spread over the Floor of the Trial Plant

which are still present in the generator gas, are extracted by cooling and washing the generator gas with paraffin oil; this cannot be seen in the schematic diagram. In this state, the generator gas goes to the pre-mentioned combustion chamber. The wash gas, being free of tar, returns again to the combustion chamber, which is arranged under the distillation shaft in order to be reheated to the distillation temperature of about 400°C. by a flame produced by generator gas with the theorteical amount of air. The wash gas taken out of the gas circuit is freed from the water vapors in the cooler shown in the

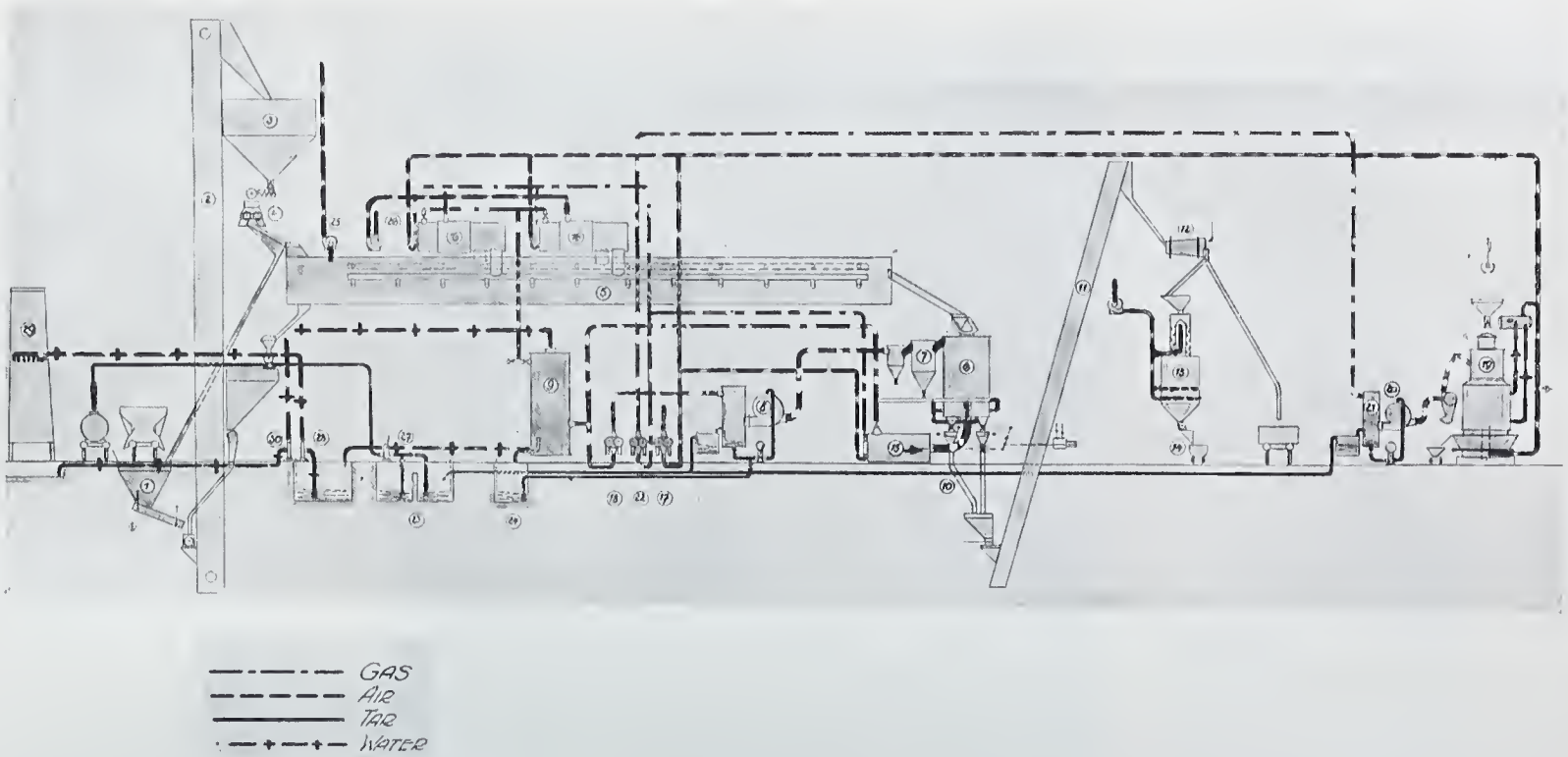


Fig. 5. Schematic Diagram of Manufacturing Process of Large Scale Production

Diagram of the detarring of the Brunswiek Coal Mines in Helmstedt Harbke Plant. *1*, hopper and slides; *2*, bucket elevator; *3*, elevated bunker; *4*, briquet press; *5*, drying eonveyor; *6*, discharge reeeptacle; *7*, dust hopper; *8*, tar washer; *9*, scrubber; *10*, eoke diseharge; *11*, eoke elevator; *12*, mixing drum; *13*, sereen operator; *14*, coke delivery; *15*, eombustion furnace for detarring; *16*, combustion furnace for drying eonveyor; *17*, blower for air; *18*, blower for scavenging; *19*, gas producer; *20*, tar washer; *21*, drop eateher; *22*, blower for gas producer; *23*, tar pit; *24*, oil pit; *25*, vapor fan; *26*, fan for secondary air; *27*, tar pump; *28*, eooling water pump; *29*, eooling tar; *30*, circulating pump.

schematic diagram. It is now submitted to a paraffin oil wash for the purpose of obtaining the light oils which are present. This cannot be seen in the schematic diagram. It is then introduced to the combustion chambers, which are arranged above the dryer. With the corresponding preheating of the wash gas and with the correct introduction of the same into the flame, which is created from generator gas and excessive air supply, it is possible easily to burn out all sulphur compounds and all combustible constituents still contained in the wash gas and to make their combustion heat available for the drying

Fig. 6. View of the Plant at Harbke Where the Freiberg Methods Are Used in Large Scale Production

process. In Figure 6 the plant in Harbke with a daily capacity at present of about 125 tons is shown.

The process described makes it possible, therefore, to execute a simple and productive wash gas process with fine earthy brown coal by the trick of forming the moist coal. Naturally, special attention must be paid to the firmness of the balls of this fine, earthy coal if the drying process and the distillation process are to be carried out without difficulties and if the coke obtained is to be coarse grained. It was found to be impossible to produce balls with a sufficient degree of firmness from certain kinds of coal that came in the moist state

from the mines, although good balls could be expected considering the structure of these coals. If the coals, however, were stored for a certain period, a certain percentage of water was lost, and the forming of the balls was made easier. It was also found in this way that preheated raw brown coal gives a firmer ball than moist coal as it is received from the mines.

In order to prove this fact, which is so important in the development of the Freiberg wash gas distillation process, the apparatus used was supplied with a fine gas dryer with filler. The output averaged between 7 to 10 tons of raw coal daily. The question of forming balls from preheated brown coal of all kinds and the behavior of these balls in the final drying to about 12 per cent moisture content, was systematically examined. This examination was important since the late drying on the conveyor and the shrinkage could be unfavorably influenced by the preceding discharge of part of the moisture. It is not necessary in this discussion to enumerate all the results obtained in the experiments with the different kinds of raw brown coal. I shall limit myself to those experiments which were conducted in the Freiberg process on a large scale. The raw brown coal used in the experiments had, at a moisture content of 47 per cent, the following composition:

	per cent
Above 10 mm	7.4
10–4 mm	50.7
Under 4 mm	41.9
	100.0

With the moist brown coal as obtained from the mine, balls with a weight of 28 grams were crushed with a load of about 3.5 to 4.0 kgm. between 2 plane surfaces. After the drying of the original product to 40 per cent moisture by passing through the fire gas drum dryer, the following grain composition was obtained:

	per cent
Above 10 mm	4.9
10–4 mm	30.5
Under 4 mm	64.6
	100.0

The amount of the fine part of the preheated coal was increased to more than 20 per cent. If this preheated coal was now pressed into

balls, and if the balls were submitted to the above pressure test, it was found that they could withstand a pressure of 11.2 kgm.

The balls produced from preheated, as well as from original moist brown coal, were submitted to a drying process in the band dryer in the careful manner described, and both kinds were dried to content of moisture of 14 per cent. For the purpose of studying their mechanical capability of resistance, the dried balls were dropped from a height of one meter into an iron barrel of 200 liters capacity. The contents of the barrel were then separated by a swinging sieve. The sieve fractions obtained in this manner are shown in the following tables:

	Balls with a moisture of 47 per cent	Balls with a moisture of 40 per cent
	per cent	*per cent*
Above 20 mm.	28.5	80.0
20–8 mm.	47.3	11.3
8–4 mm.	14.2	3.9
Under 4 mm.	10.0	4.8
	100.0	100.0

The difference in size is very great. The balls from preheated coal furnish more than 50 per cent larger pieces than the balls from moist coal, if both are dried to the same content of water. This examination, which was confirmed by many tests, showed distinctly the great advantage of partial preheating of the raw brown coal before the forming of the balls and of careful drying on the band dryer. With the further drying of the raw brown coal to a moisture content of 35 and 30 per cent, respectively, an increase in the firmness of the balls to a pressure of 13 and 19 kgm., respectively, was obtained. The content, however, on grain above 20 mm. was less—namely 60 and 46 per cent respectively—in the examination of the balls dried to a 14 per cent moisture content. The portion of the grain is, however, better than the corresponding portions of the moist coal as received from the mine. The desirable qualities of balls produced from brown coal are not only shown in the drying process but also in the distillation process. While previously the balls produced from the raw brown coal as received from the mine caused a decrease in pressure of 200 mm. water column in the distillation process, there is now, in using balls produced from preheated raw brown coal, a decrease in pressure of only 80 mm. The same pressure must be employed if

high pressure brown coal briquets are carbonized in the same distilling shaft and under the same conditions.

The process described above, however, puts the Freiberg method of wash gas distillation on a very improved basis. While atmospheric conditions are not without a certain influence on the formation of moist earthy coal into balls, still the fluctuations in this type of coal are easily overcome by adding the predrying method, since very good firmness can be obtained, if coal is predried to 30 per cent moisture. As balls which have been produced from preheated coal are characterized by greater firmness, much less attention has to be paid to storing, drying and transportation of them to the distillation shaft than with balls formed from moist brown coal. Nevertheless, production with balls of the original coal is possible and entirely satisfactory as it is shown in Freiberg and Harbke.

A preliminary drying of the moist brown coal is not a complication of the whole process, since the fire gas dryer is greatly aiding the belt dryer. This is of particular value, however, as it gives a reliable method of separating the tar from the amorphous brown coal, which often contains a higher amount of bitumen than lumpy brown coal or lignite. It is well known that by retort methods this can be only partly accomplished, if at all. In vertical rotary retorts only screened dry coal can be used, since very fine dry coal transfers into the tarry condenser. The contamination of the tar by dust in retorts of the rotating drum type is, however, possible. In this case the utilization of the tar at reasonable prices becomes questionable.

We see that the drying of coal with a high content of moisture in the low temperature carbonization process is very important, if earthy brown coal or lumpy lignite is used. The same attention must be paid to the low temperature carbonization of dried coal if the advantages consist, as we know, principally in the simple, efficient, and cheap apparatus. It is very important for the whole process to use a charge of uniform size. Therefore it must be considered whether it would be better to separate the brown coal, by screening, into lumps and fine coal, and treating them separately. With respect to the behavior of the balls during drying and the following low temperature carbonization, we probably will often prefer to crush the original coal, if the earthy part is large, in order to get only one material for the carbonization. Sifted lumpy coal at a size of 20 to 35 mm. is not so uniform as the balls produced of the crushed coal. The small additional cost for crushing the brown coal is more than equalized,

because we have then only one material for distillation and this material is absolutely uniform.

The German brown coal distillation industry, during recent years, has been making efforts to conduct the low temperature carbonization process in such a way as to produce a distillation residue which is particularly high in gas, easily inflammable, and which burns with a long flame. This is demanded especially from the combustion engineering standpoint, and the application of gas as heat transmitters and washing media with their partial pressure-lowering action meets this requirement very well. As it is shown, tar can be removed from suitable dried brown coal at temperatures of about 400°C., if a sufficient amount of hot gases pass through the shaft. Under these conditions a degasification of the coke does not take place, and the coke is obtained with high contents of volatile constituents. This is another advantage of the wash gas carbonization, because the quantitative elimination of the tar from coal takes place without a considerable formation of combustible gases. The gases formed consist principally of carbon dioxide and hydrogen sulfide. The heating value of the distillation gas usually does not exceed 2 per cent of the total heating value of the moist brown coal if the wash gas process is conducted in the right way.

From technical and economical viewpoints it is advisable to conduct the tar removal in such a way that any formation of combustible gases is avoided. If the production of gas of a high quality is desired, it is advisable to submit the hot coke to a special degasification process directly after the tar removing process. Carrying on both processes independently, it is possible to eliminate during the tar removal the largest part of the worthless, incombustible gases. By these means a decrease of the heating value of the high quality gases which formed during the degasification process is avoided.

It is possible to obtain a gas of about 4,200 kgm. calories per cubic meter in the degasification of wash gas coke, produced from brown coal. The amount of gas obtained at 800° to 900°C. is about 200 cubic meters per ton of coke.

The coke obtained in the low temperature carbonization has a large internal surface because of the high water and tar content of the brown coal and the special manner in which it is produced. A large internal surface also increases the activity of coke.

The reduction of carbon dioxide passing over coke of the quality described at different temperatures is interesting. Figure 7 shows

the curve of reduction of the carbon dioxide measured by the volume of the carbon monoxide formed in relationship to the temperature. For comparison the reduction of carbon dioxide by usual high temperature coke of coal is given in the same diagram. The coke of

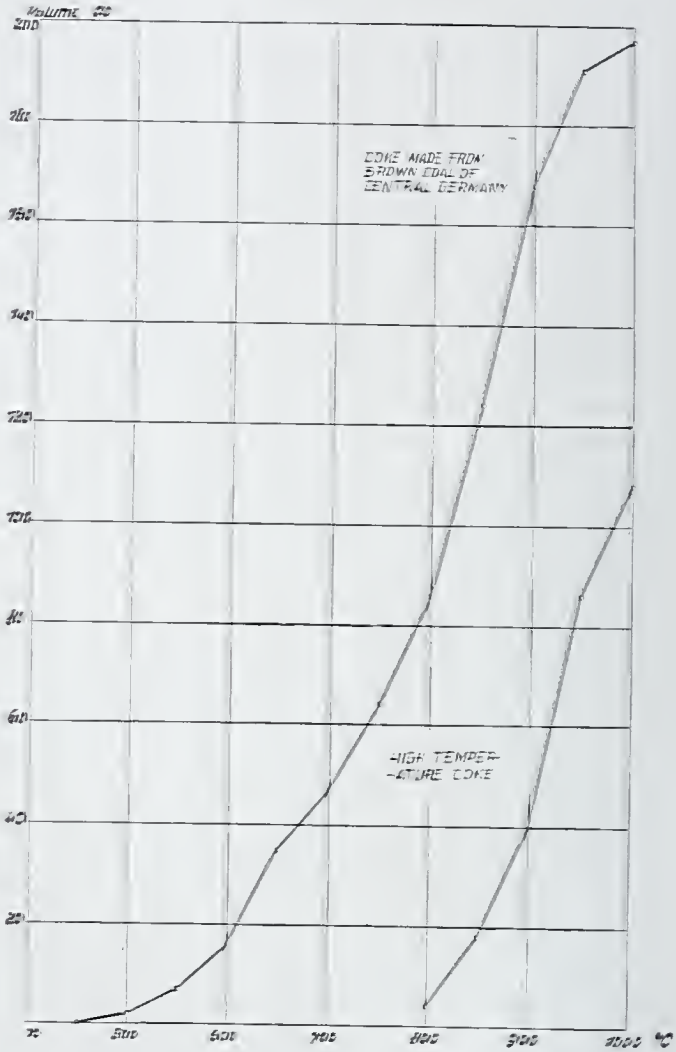


FIG. 7. DIAGRAM OF CURVE OF REDUCTION OF CARBON DIOXIDE, PASSING OVER COKE, AT DIFFERENT TEMPERATURES

brown coal shows its reducing action clearly at temperatures of 550°C. This only occurs to the same extent with high temperature coke, until 800° are reached. At this temperature the reducing action of the coke of coal is just beginning, while wash gas coke from moist brown

coal or lignite has already reduced 42.5 per cent of the total carbon dioxide. Normal coke is not able to reduce the same percentage until temperatures of 950°C. are reached.

This favorable behavior makes the coke of high moisture coals particularly suitable for generation of water gas, since water vapor is reduced fast at comparatively low temperatures, similar to carbon dioxide.

For this purpose, and also for the direct combustion of undegasified coke from moist coal a more or less uniform size is necessary if the combustion is to be carried on in industrial furnaces. This granularity cannot be obtained in the low temperature process with retorts because the wet charge must be dried as quickly as possible. The wash gas processes, however, make it possible to produce a coarse-grained coke if the drying process is carried on in the right way, and the simple shaping process described in a briquet press is used on amorphous coals. As numerous combustion experiments have shown, this coarse-grained coke of moist coal can be burned easily in large scale plants with good efficiency. Particularly suitable are the mechanical furnaces such as furnished by Frankel and Viebahn at Leipzig and chain grate furnaces built by the well-known German steam boiler company L. and C. Steinmuller, Gummersbach. If the precautions mentioned are disregarded a fine grained coke is obtained. Such material must however be powdered before it can be used industrially as powdered coke. The powdering of low temperature distillation coke requires, because of its hardness, a higher power consumption and wear than the pulverizing of dried brown coal.

The greater reactivity of the brown coal coke is the reason for greater spontaneous combustibility. Even when containing 10 to 12 per cent moisture and cooled to room temperature under exclusion of air, this coke is apt to ignite spontaneously after admittance of air. The process of spontaneous combustion occasionally takes place so fast that after 10 to 15 minutes the surface of the coke starts to glow. Dr. Jappelt,[2] one of my collaborators, and other investigators have shown in recent publications that heating, caused by oxidation precedes spontaneous combustion. The spontaneous heating is usually caused by the oxidation of sulfides, for example, iron sulfide; the temperature of the coke increased until the oxygen of the air starts to react with the coke. The heat generated soon brings the coke to its ignition point of about 140°C.

[2] Jappelt, *Braunkohlenarchiv* 1928, Number 20/21.

Dr. Jappelt has also shown that the spontaneous combustion of coke produced from moist brown coal can easily be avoided. For this purpose the coke is cooled in the shaft to 150° with cold wash gases. The coke so prepared is then saturated with 10 to 12 per cent water in a mixing drum. After this the coke is treated with limited quantities of air in a simple air cooler for about two hours, so that oxidation and cooling of the coke take place simultaneously. Coke treated in this way must, however, undergo additional treatment of about 30 hours in a so-called oxidation bunker where small amounts of air remove the last tendency to spontaneous heating and spontaneous combustion. We have seen the arrangement of the mixing drum, the air cooler and the oxidation bunker in the scheme of the large tar separating plant, Harbke, which uses the Freiberg process. The oxidation process can be conveniently controlled by the addition of the previously mentioned limited amounts of water. If the drying and the tar separation are conducted in the way I have described the oxidation process is considerably simplified, because the coke produced according to the Freiberg process has a coarse grained structure. This lumpy nature of the coke permits the use of simple and efficient apparatus because sufficient contact with the air can be obtained even with slow settling of the charge.

In the case of such a careful treatment no appreciable crumbling of the coke takes place.

For certain purposes, such as domestic fuel, the brown coal coke is probably still too soft, because it naturally cannot have the hardness of metallurgical coke. Therefore a briquetting of the coke has been tried and considerable success can be recorded in this line. Two reasons made the usual application of tar pitch as a binder impossible: first, the coke would lose its valuable property of a smokeless and a sootless fuel; and second, pitch manufactured from low temperature distillation tars cannot be used without a certain preliminary treatment, as it possesses only partly the adhering and cementing property of the bituminous coal pitch. It would also be possible to use coal tar pitch as a binder and eventually to extract again the oily constituents of the tar by another heating; this, however, makes the briquetting too expensive. It has been tried therefore to use cheap inorganic binders like Zellpech, clay or calcined magnesia, and the waste products of the fabrication of cellulose. Coke briquets of great hardness can be manufactured if the right amounts of these materials are used in preparing the binder. In spite of the increased ash con-

tent, these briquets are easily burned and also are comparatively resistant to water. The cost of this briquetting still is too high. Investigations carried on in the Brown Coal Research Institute in Freiberg have shown, however, that it is possible to do the binding with water alone in amounts of 10 to 14 per cent. The Eseter presses of the modern brown coal briquetting industry, which are turning out large outputs and generate pressures of up to 1,800 kgm. per square centimeter, can be used conveniently. Corresponding laboratory experiments have been carried out. Large scale tests will be conducted soon with a normal briquet press of 50 to 70 tons daily capacity in the experimental plant which is supervised by myself.

It should be mentioned that in this type of briquetting a small part of the tar producing substance has to remain in the coke. For this reason the single coke particles are more mobile after being wetted with water, and form hard briquets. Investigations have shown, however, that the remaining part of the low temperature distillation tar consists mostly of resin-like materials. These constituents are not valuable. It is true that the yield of tar decreases very slightly, but the produced tar has a higher paraffin content, because at these temperatures the valuable paraffin is rapidly leaving the coal. We see that the resin-like constituents of the tar can be left in the coke since they do not decrease the efficiency of the process and even furnish a more valuable tar. The most careful watching of the distillation temperature is of the greatest importance for a successful coke briquetting with water as binder. In wash gas process this is not difficult, as extensive investigations both in the experimental plant and the large scale tar separation plant in Harbke have shown.

Coke briquets with water as binder show approximately the same firmness as those manufactured from dry bituminous brown coal. Coke briquets also resist damage by water. The small amount of tar which is left purposely in the coke causes no formation of soot or smoke.

In order to give a complete review of precautions, which have to be taken in the low temperature distillation of moist coals, I must also mention the question of annoyance by obnoxious gases and the quantitative and efficient neutralization of waste water. Shortly before my departure from Germany the question was brought up again when the civil authorities ordered the closing of a large low temperature distillation plant because of the annoyance to the densely populated neighborhood.

As I said before, the extremely small amounts of low temperature distillation gas which are formed during the tar removal, are burned in the combustion chambers which belong to the drying apparatus and in this way they are utilized for the drying of the coal. They form the usual combustion products and do not pollute the atmosphere. Another source of small amounts of hydrogen sulfide and carbon monoxide might be the secondary cooling of water. This water is used for washing producer gas and tar-free wash gases before they enter the paraffin oil washers for separation of the benzine products. In all investigations no free hydrogen sulfide could be detected in the warm cooling water which comes from the dripping cooler. This corresponds well with observations of vapor air mixtures coming from the water cooling tower, where hydrogen sulfide could not be detected either by its odor or by the most sensitive reagents. The complete absence of hydrogen sulfide in the cooling water may be explained by the formation of elementary sulphur. The hydrogen sulfide formed during the tar separation process reacts at the moment of formation with the sulphur dioxide of the wash gas, which arose from the combustion of the hydrogen sulfide contained in the producer gas.

The escaping of carbon monoxide from warm cooling water cannot be expected, because the solubility of carbon monoxide in warm water is extemely small. These small soluble amounts cannot escape, because the solubility of carbon monoxide in cold water increases. Even the large amounts of air, with their partial pressure reducing action, cannot greatly influence these conditions.

The atmosphere will not be polluted by obnoxious gases if the low temperature carbonization of high moisture coals is carried on in the right way, especially by the Freiberg process. The typical odor of brown coal tar in the low temperature distillation process does not justify the conclusion that the process is harmful to health.

Waste water from low temperature distillation plants of brown coal is dangerous for the fauna of the rivers not so much because of the poisonous action of the small amounts of dissolved phenol, as because of the high oxygen absorbing properties of these phenols. The action of the phenol-bearing waste water is analogous to that of the alkaline pyrogallic solution used in the gas analysis. This becomes dangerous, however, only when the waste water is alkaline or becomes so, on account of the alkalinity of the original river water.

The waste water question cannot be considered as dangerous in

the future utilization of moist brown coal or lignites. This has been definitely shown by the more than six months of operation of the large separation plant in Harbke, which uses the Freiberg process. In the drying process about 85 to 90 per cent of the moisture of brown coal can be removed in the form of water vapor. The remaining 10 to 15 per cent moisture of the dry coal and the water which forms during the distillation are removed quantitatively by vaporization if the cooling tower is properly designed. As we see, a waste water question did not exist at all in the tar separation plant in Harbke and according to all evidence it will not arise in the future either in this plant or in any other to be built.

I have tried to give an outline of methods which will allow a particularly economical utilization of high moisture coals such as the German brown coal and the foreign lignite. The expensive investigations were made possible by the financial aid of the State of Saxony, and the German brown coal industry particularly interested in the prosperity of the State Brown Coal Research Institute in Freiberg. It is true these brown coals and the lignites are usually described as inferior. The high water content and the small mechanical stability as compared with coal, seem unfavorable for their extensive utilization. We must not forget, however, the extremely great amount of valuable bitumen often contained in the brown coal. The separation and utilization of this bitumen opens a greater economic possibility than the bitumens of bituminous coal. The coke produced by a suitable low temperature carbonization process from high moisture coal is in the state it is produced and after briquetting, not only an excellent fuel but also a material of high reactivity. Lack of time does not permit discussion of numerous possibilities for chemical utilization of the low temperature distillation products. This can be done at a later occasion.

MANUFACTURING BITUMINOUS COAL FROM PETROLEUM

By Dr. Walter F. Rittman

Carnegie Institute of Technology

To appear before this Conference, which is largely devoted to the manufacture of petroleum from coal, with the description of a plant manufacturing coal from petroleum requires real courage. However, it is a poor rule which does not work both ways, and further, I hasten to say it is unlikely that the coal industry will be demoralized by competition from the operation I am about to describe, nor that those interested in the main theme of this Conference need be seriously concerned. On the contrary, it is my belief that the coal I am about to describe may prove to be an ideal starting material or raw product, either alone or mixed with other coals, for their processes of converting coal into petroleum. As matters now stand, one important American oil refinery is planning to provide facilities to convert its crude petroleum entirely into gasoline with the manufacture of some coal as a by-product. With the combination of processes I have indicated above it would by no means be difficult to visualize a plant capable of converting the *crude petroleum entirely into gasoline.* Probably I am not the renegade one might conclude from the title of my paper.

The first question which naturally arises is: "Is it commercial?" For a period of months the plant in question has been manufacturing some fifty tons a day of the material. Facilities are now being provided to increase this to one hundred tons a day, with plans under way to considerably increase that output; the balance sheet is decidedly in the black, but these statements do not answer why it is commercial. To answer these questions it becomes necessary to briefly describe conditions, more particularly those existing in the United States Midcontinent section, pertaining to gasoline production and fuel oil markets. Despite the predictions, widely published, made some five years ago by a prominent committee to the effect that America's oil supply would be exhausted in some six years, the American petroleum industry is today facing a serious menace in a potential avalanche of "shut-in" crude petroleum. To the credit of the industry, it is becoming the practice of oil refiners to handle

only such quantities of crude oil as can be refined efficiently and profitably. Whereas, not many years ago the average production of gasoline from crude oil was well below 20 per cent, it is by no means unusual today to find refineries converting 75 to 80 per cent of their crude oil into gasoline. This is achieved by what are known as cracking processes. The "skimming plant" which merely distilled off the gasoline from the crude oil and sold the balance as fuel oil no longer can compete with the more complete refinery.

Low grade fuel oil at the present time in the Middle West is selling for about $1\frac{1}{2}$ cents a gallon, and during the past six months quantities have been sold for as low as $\frac{62}{100}$ cents a gallon. When, with a manufacturing cost of a few cents a gallon, it is possible to convert considerable portions of this fuel oil into gasoline, then it at once becomes obvious that the goal of the progressive refiner is to produce a maximum of gasoline and a minimum of fuel oil from a given quantity of crude oil, particularly since he receives for a gallon of fuel oil only a fraction of what he pays for crude petroleum. Moreover, other conditions prevailing and developing in the Midcontinent, point strongly to a depressed fuel oil market. Coal is cheap. Despite the cheapness of coal, however, another factor looms big over the horizon. I refer to the long-distance piping of natural gas. Within the next year literally hundreds of millions of cubic feet of natural gas originating in Texas, Montana, and other states, will daily be delivered to the great fuel consuming centers of the Middle West. Pipe lines for months have been delivering natural gas originating in Texas to Denver together with the cities en route. Pipe lines are now being laid to connect Texas and Kansas City, supplying cities en route. Plans are being discussed to continue the lines to Chicago. A project, financed by another company, to pipe natural gas from Texas to Omaha, Nebraska, and other cities en route is about to be consummated. Announcement has been made of a project to pipe natural gas from Montana to Utah and California. It appears now that in relatively few years a large portion of the Middle West will have available natural gas at prices low enough to offer serious competition to coal, and ruinous to the petroleum refiner having large quantities of fuel oil to sell. In short, the problem of the Middle West petroleum refiner is, and very probably will continue to be, "Make more gasoline and less fuel oil from a given quantity of crude oil," and it is as a by-product of this situation that the manufacture of coal from petroleum refuse is made commercial.

The quantity of gasoline required appears to be of constantly increasing proportions. With almost thirty million automobiles, the United States in 1929 will produce well in excess of fifteen billion gallons of gasoline, with an annual increase of—roughly—10 per cent.

As a by-product of the cracking process at the plant to which I will now refer, there is produced a refuse oil, fuel oil, considerably heavier than water, and containing considerable solid matter. Lime is used in this particular cracking process and this lime concentrates in the refuse and constitutes a part of the solids referred to above, the balance being free carbon, etc. The problem was to recover the oil present in this refuse at a minimum cost in order to make more gasoline from the recovered oil. A common practice is to charge this refuse to shell stills, called "coking stills" in the art, put a fire under the still and continue heating until only coke, with very low volatile matter content, remains. This "batch" procedure requires a big investment in stills, depreciation and maintenance is high, and the coke must be removed manually with a variety of implements. The cost of recovering the oil is real, both with respect to investment as well as labor and maintenance. In the present operation the refuse oil is pumped through a long continuous coil (about 3-inch inside diameter and several thousands of feet long) placed in a furnace, known in the art as a "pipe still." The end of this heating coil leads to a chamber, from the top of which the vaporized oil is led to a condenser and recovered, and the "bottoms," while very hot and still in fluid condition, are pumped to any desired point, and, in fact, can be pumped directly into the car in which shipment is to be made. By controlling the rate of flow through the coil, as well as the furnace temperature, neither of which are difficult, one can readily control the percentage of volatile matter left in the residue. This percentage of volatile matter left in the residue naturally will be primarily influenced by market and operating conditions. The analysis of a typical residue which congeals into an amorphous bituminous coal follows:

Volatile Matter	45 per cent
Fixed Carbon	51 per cent
Ash (Lime, etc.)	4 per cent
B. thermal units per pound	about 15,600

The operation appears to be practically continuous, in that runs of two to three weeks' duration have been common. With manual

labor of practically negligible proportions, since no manhandling is involved; with low investment cost as compared with coke stills; and with relatively low maintenance cost, it becomes apparent why the operation is commercial. One could almost afford to give away the coal. However, this is by no means necessary. Large scale tests are under way and it already appears that this coal is most desirable for coking purposes to produce metallurgical coke. The reasons for this are apparent when one considers the character and low percentage of ash, together with the fact that the coal is low in sulphur.

In addition, large scale experiments are under way wherein the material is being pulverized before burning under boilers and in cement kilns; also a large boiler is being equipped with a type of rotary burner used in oil refineries. Also, as previously stated, I feel that this material might be an admirable raw product for the processes which propose to convert bituminous coal into petroleum, which petroleum in turn could by present methods be converted entirely into gasoline with small quantities of more coal, thereby creating a cycle and bringing to reality the desire of progressive petroleum technologists; i.e., *to convert crude petroleum entirely into gasoline.*

TRUMBLE LOW TEMPERATURE CARBONIZATION PROCESS

By Colonel J. W. E. Taylor

San Francisco, California

The development of the Trumble Low Temperature Carbonization and Distillation Process, had its inception about eight years ago, when Milton J. Trumble, an inventor of established reputation in the development of distilling and cracking processes and apparatus in the oil refining business, was asked by certain western oil producing and refining companies, to determine an economical method whereby the hydrocarbon values could be recovered, from the vast deposits of oil shales and lignites within the continental United States.

Mr. Trumble, very early in his research work, demonstrated the practicability and desirability of utilizing the principles involved in distillation under pressure. As his empirical determinations indicated the values which would be evolved from a controlled variation of the combinations in temperature and pressure, he turned to superheated steam as a heat transfer medium, and this process is built around the control of the foregoing factors.

In effect, the process consists of the following apparatus cycle (Fig. 1):

The raw material passes from storage bins into thermostatic-controlled, preheating chambers where the raw material is preheated and dehydrated by utilizing the products of combustion from the boilers and superheaters. The vapors from the preliminary dehydration are passed directly to condenser apparatus.

From the preheaters the material is fed, by batching or intermittent delivery, into the distilling apparatus.

The charging and discharging gates, to retorts, are the Trumble interrupted thread artillery breech block type of valve. These valves are self cleaning as to foreign particles in thread grooves and are insulated against excess heat action.

The gate, at the lower end of the retort, is of same opening diameter as body of retort.

This type of gate is a separate invention, by Mr. Trumble, and is in general use in some forms of refining practice, and on tanks, tank cars, etc.

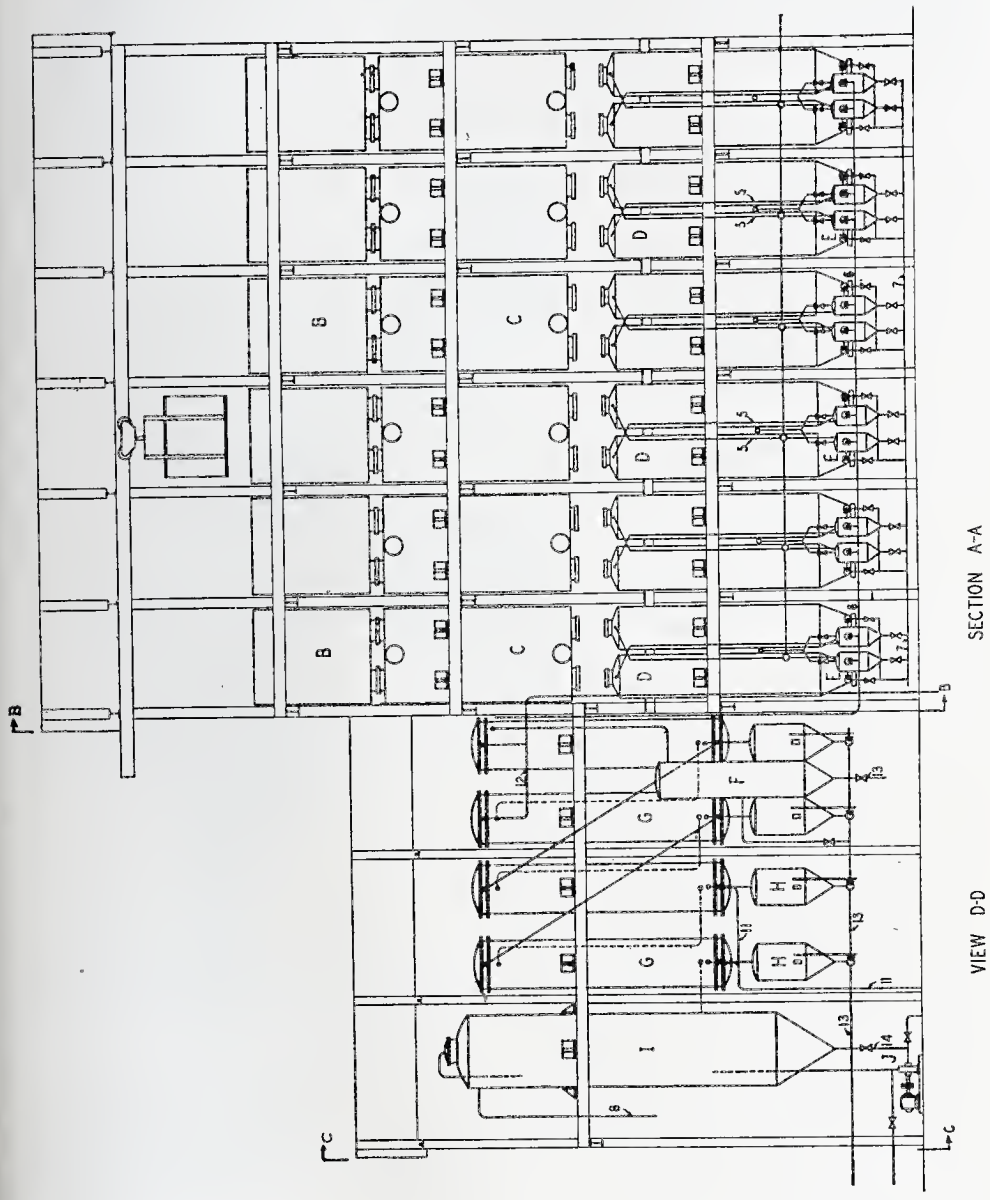


FIG. 1A

We have learned through the development and the experimental work involved that the ideal size for this retort is somewhere around 200 cubic feet capacity, and that the relative dimensions are diameter about 30 per cent of the length. This determination has been predi-

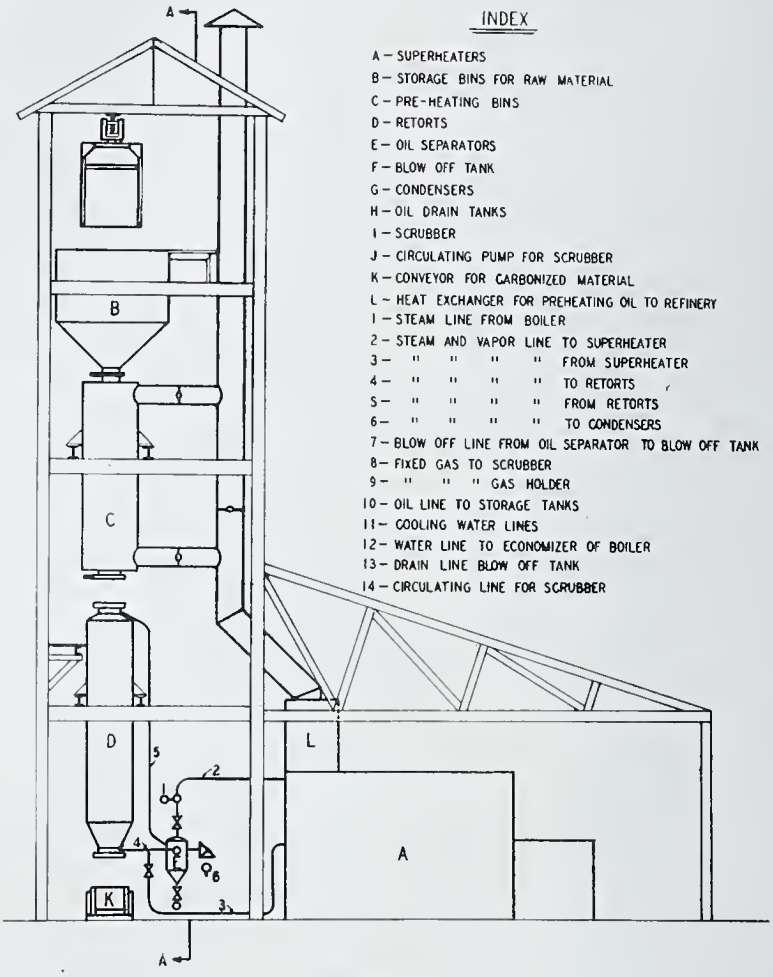


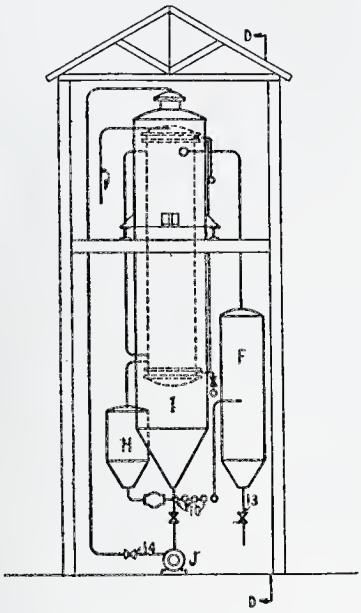
FIG. 1B

cated upon experimental work having to do with the heat action within the mass.

The distilling apparatus consists of a bank of retorts set in batteries of two, and each bank may consist of such a number of batteries, as the practical application of the process, through pilot plant operation, has heretofore determined as being the most efficient combina-

tion for handling the material involved. These batteries of retorts are interconnected, so that any cycle or combination of cycles can be maintained, and each battery is connected to a superheater.

The preliminary steam requirements are very small, as the process develops in its cycle enough steam through dehydration to build up and maintain the volumetric requirements for handling the process.



VIEW C-C

FIG. 1c

The steam from the primary boiler, after being superheated to the temperature necessary in the pressure combination for producing the required proportions of primary products, passes through a hydrogenator and thence into the first battery of retorts, which are connected in series; from this battery the steam from dehydration, fixed gases, vapors and the entrained particles of oil, pass through an interstage oil separator before entering the second interstage superheater.

In this interstage oil separator all the condensates, liquids and particles of oil are taken off and at loading intervals discharge into the cooling apparatus.

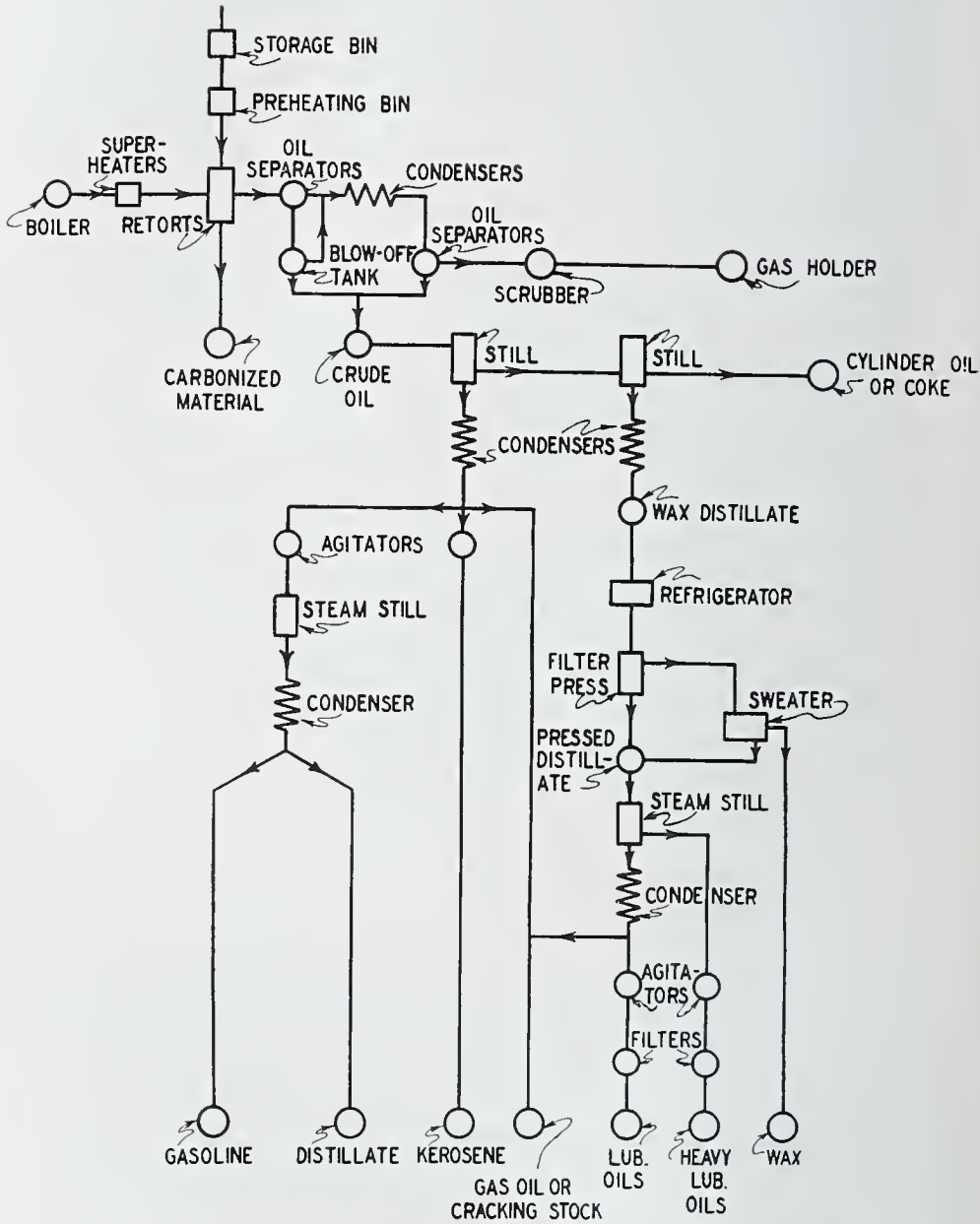


FIG. 2. FLOW SHEET OF TRUMBLE CARBONIZATION PROCESS

In the second interstage superheater, the temperature of the steam, vapors, fixed gases, etc., is again raised to maximum temperature requirement. This combination of items now passes through the next battery of retorts, again giving off its heat to the raw material, distilling off the volatile contents thereof, and then passes through the second interstage separator before entering the third interstage superheater.

This process is repeated until the original steam has been passed through all of the batteries of retorts. In this manner the same steam has been superheated between each battery and, together with the fixed gases and other vapors involved, has been continuously passed from one battery of retorts to the next; in each retort is given off a certain amount of heat, the quantity of which depends upon the remaining degree of distillation required for handling the material in each particular retort. It will be seen that the temperature of the raw material in the first retort is the highest and that the temperature becomes lower as the last activated retort is approached. Practice has demonstrated that this method of maintaining a gradual rise in temperature curve within the retorts furnishes a definite control as to quality of products. The cycle is automatic so that as soon as the temperature of the raw material in the first battery has reached the point required, this battery is emptied and refilled and then automatically goes back on the end of the cycle of steam circulation, so that the second battery of retorts now becomes the lead battery and receives the charge of fresh steam first.

This system of cycling is so arranged that each retort in the battery is a complete time cycle removed from its mate, so that at all times the back pressure effect of the difference in temperature between each pair of retorts is operative. Since each retort, as above indicated, is cleared to point of maximum temperature, the cycle is ended for that particular retort, and the vapors, gases, steam, etc., are conducted to the condensers and coolers by way of the necessary heat exchange apparatus.

In our work on Manchurian coals in Yokohama, we found a time cycle on a basis of twelve retorts of about 122 minutes for the complete distillation in carbonization. So that with 122 minutes total time cycle on that particular material, and in developing certain predetermined products, we have, after the first period of 22 minutes, one retort coming on and off every ten minutes without interruption.

Semi-commercial, pilot plant operation has demonstrated that

the cycling, within this process, is readily made automatic by thermostat control of quick-acting valves; this in turn is augmented and protected by a complete manual control.

The quick acting gate valve, above mentioned, was invented by Mr. Trumble and has been in general use, for many years.

The flexibility and adaptability of this process, in making primary recovery of products, now becomes evident when the absolute control of pressure and temperature, through interstage superheat, is understood.

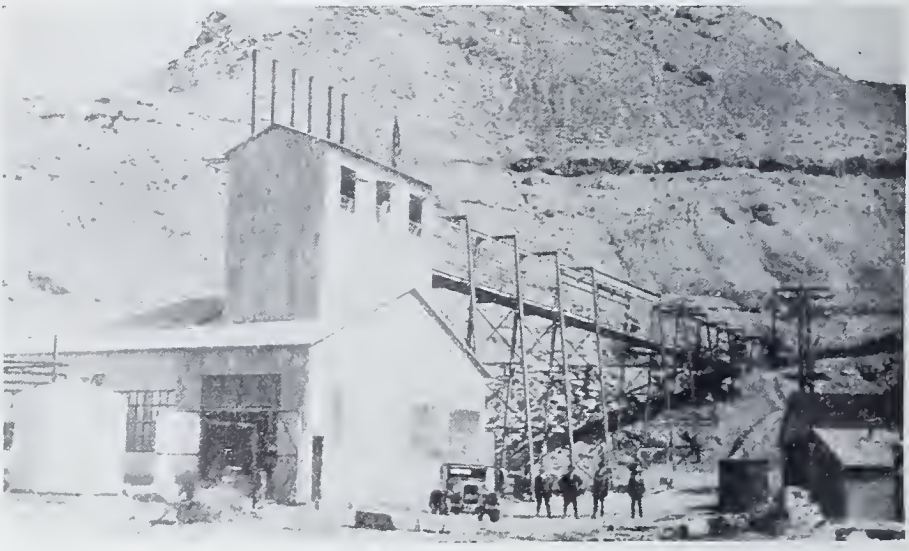


FIG. 3. TRUMBLE CARBONIZATION PROCESS, GREEN RIVER PILOT PLANT, WYOMING

Quantity and quality range curves have been empirically determined and proven and it is demonstrated that any combination of the foregoing is available, from the operation of this process.

In the operation of this process, there has been delivered a series of primary products, and the process is peculiarly adaptable to its series operation ahead of any one of the many cracking devices and other principles now available for the recovery of the secondary or refined end products.

To illustrate, in the handling of bituminous coals, we have as major primary product, a type of open grate coke, which has been produced at a low temperature, and which is capable of being ignited in the same manner as coal. This item simplifies the problem of

storage, as the grate fuel product from this process carries an exceptional B.t.u. content, and which may be stored, without deterioration, for an indefinite period of time. This item also solves the problem of domestic fuel, being smokeless, of high heating value, and its relatively low cost of production permits of competition with gas in most districts.

This process lends itself to the production of a free burning grate coke varying in size from nut to lump and the expense of briquetting is avoided.

The end products from bituminous coals consist of gasolines, naphtha stocks, benzol stocks, fixed gases, creosotes, sulphurs, ammonias, coal tars, etc., depending upon the analysis of the raw material and upon the predetermined treatment under this process, and under the series end-process.

To illustrate, there are no finished coal measures in the state of California. Probably the best coal measure known is the Stone Canyon measure, and it runs about 4.5 per cent by volume in sulphur, and is absolutely useless as a steaming coal. This process delivers from that coal approximately 61 per cent of semi-coke, such as I have described, which runs 14,300 B.t.u. By varying the temperature and pressure, and by keeping down as lean as possible on the amount of fixed gases, and handling our hydrogenation at the proper point, with the proper amount of filtration we can get a high B.t.u. fuel, but the coke is not the main object in this case. Of course, it is a valuable thing, but the point I want to bring out is the value of the other products.

This process gave for that useless coal about 12½ gallons light gasoline at 150°C., and made an ideal coke. It also gave about 10½ gallons of "lub" stock. It gave 25 pounds of ammonium sulphate to the ton, and it also gave about 6 pounds of creosote and about 82 pounds of sulphur.

This process produces no coal tar residues, at carbonization temperatures. When the Trumble vapor-phase refining cracking process is used, as a series end-process with the foregoing, there occurs a residue end of coke, amounting to about ten per cent by weight of the amount of oil put through the cracking process. This item is classified with the balance of the coke produced.

This process delivers an ideal domestic or grate fuel coke, as a primary product from impure bituminous coals, which cannot, in their mine-run state, be economically used.

This process has demonstrated its adaptability and economy as a primary process for the recovery of resins, pine oils, alcohols, etc., from the waste of the lumbering industry, in the utilization of logging residues and milling residues. The process delivers, as a primary

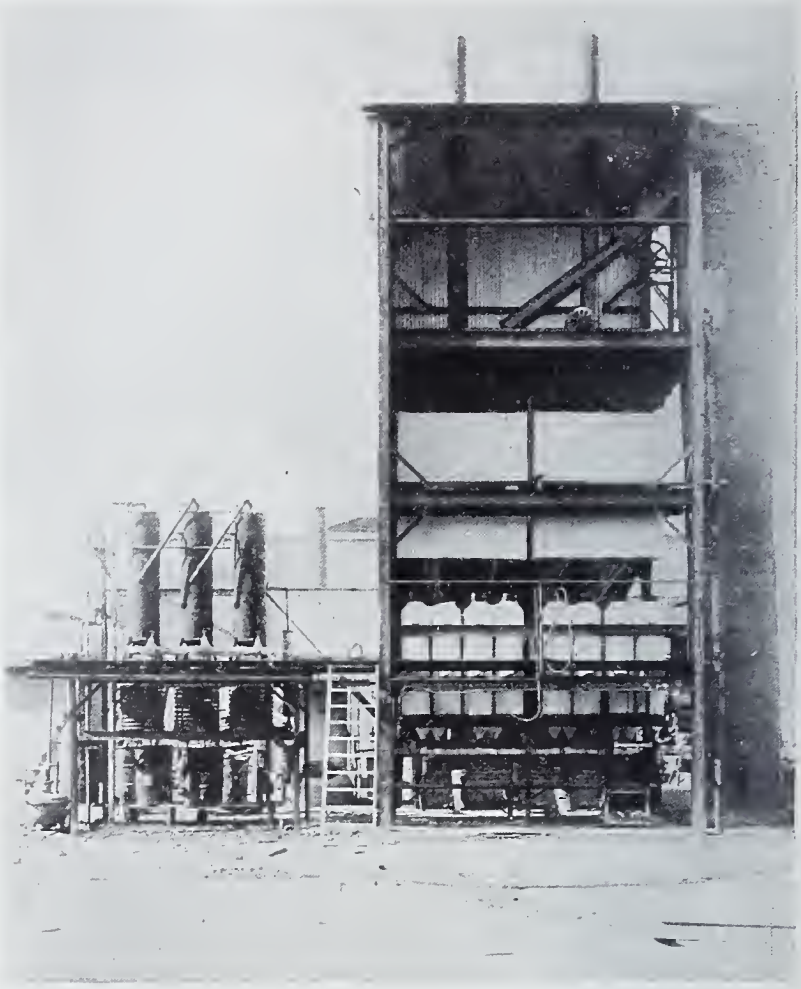


FIG. 4. PILOT PLANT BUILT AT OAKLAND, CALIFORNIA, DISMANTLED AND SENT TO YOKAHOMA

product, a commercially pure fuel charcoal. This application of the process is of vital importance in utilizing the full resources of countries now having high population-density factors.

The foregoing statements are predicated upon some eight years of intensive research and experimental work, and the commercial appli-

cation of the process has been determined through the construction and operation of a series of pilot plants and semi-commercial plants.

An experimental pilot plant is maintained at the company's laboratories in Alhambra, California. A pilot plant of semi-commercial capacity has been built at Green River, Wyoming, and used for making practical demonstrations for the handling of the various oil shales within continental United States.

A pilot plant, of semi-commercial capacity, has been constructed in Yokohama, Japan, and is being used for making practical demonstration of the values involved in treating the coals, lignites, and oil shales of Japan, Manchuria and Korea. It is intended this plant shall be used in working out the problems of handling organic wastes, and in utilizing the limited amount of fagotage or domestic fuel supply, so that certain fundamental primary products may be taken therefrom and a clean charcoal residue left as a domestic fuel. This work is being done by Japanese interests, and much of it has to do with the solution of their problems, involved in undue economic stress, which is accruing as a result of their high population-density factor.

Economic stress now setting up as a partial or whole control in many industries and, which is now indicated in some of our important industrial sections, can be met through the adaptation of this process.

It is believed that the past eight years of experimentation, development of process methods and application, and pilot plant operation on a representative series of the coals, lignites and shales of western United States, Canada, South America and Asia, as well as the long series of varied tests upon the waste products of the logging and lumbering industry, definitely places the Trumble Low Temperature Carbonization and Distillation Process in a position where it may be set apart by the following summarization:

1. Demonstrated low cost and operating expense.
2. A minimum in number of moving mechanical parts.
3. Flexibility and adaptability of process—treatment of various materials, without change of plant design or construction.
4. One hundred per cent recovery of primary products of superior quality.
5. Production of finished end-products made ready for market through utilization of process in series with any of the proven cracking, refining, distillation and/or carbonizing units now available.
6. This process carries the right for use, as a series end-process, the Trumble cracking and refining processes, including Mr. Trum-

ble's latest hydrogenation and vapor-phase cracking and refining process.

It has not been possible, in this short paper, to enter into a discussion of the detail of the cycle or phase operation of this process, and the writer has been compelled to confine his discussion to a general description of the process, its development and operation, some of its empirically determined applications, and its indicated further fields of use.

The writer first came into contact with the Trumble Low Temperature Process while engaged in research work having to do with the development of a method for utilizing the waste materials accruing to the logging and milling operations of the lumber industry.

This contact has been maintained for more than five years and he has had occasion to watch the development of the Trumble Low Temperature Carbonization Process and has intimate knowledge of the specific detail involved. It became apparent, some three years ago, that the flexibility and adaptability, of this process would ultimately place it in a position of major importance in handling problems covering the reclamation of organic waste accruing from our industrial development.

This is an item which becomes more important as a factor in the stresses of competitive production in proportion as the raw product involved is depleted.

It is not thought that this argument should be applied to the coal industry, but rather that the utilization of this process, in connection with the coal industry, should be predicated upon the principle that the primary derivatives shall be recovered at a maximum efficiency and minimum cost and that the resulting residue of carbon in the form of a high B.t.u. content coke, which has been produced at low temperature, shall be made available for storage and distribution without depreciation losses. It is believed that this method of utilizing the Trumble Process will go far toward solving the difficulties of, and eliminating the losses from, the present and prospective periodic labor supply and market demands.

Further information, charts and graphs may be had from the company's laboratory records, and commercial application records at 610 South Broadway, Los Angeles, California.

DISCUSSION

T. G. WEBER (Central Union Gas Company, New York, N. Y.): I did not quite understand where the spontaneous combustion is apt to take place in the coking process of brown coal.

F. SEIDENSCHNUR (Mr. Hilt interpreting): The spontaneous combustion only takes place if the coke is not carefully quenched. In some instances it even undergoes a certain oxidation. The waste gas still contains some oxygen and the sulphate present catalyzes oxidation, leading to spontaneous combustion.

MR. WEBER: I understand that it takes place in storage only if it is not carefully cooled.

CHAIRMAN ANGLOCH: I would like to ask Mr. Seidenschnur whether all of the equipment used in his process is of German manufacture?

MR. SEIDENSCHNUR: Certainly it is all of German manufacture, and it is all standard equipment and can be readily obtained. All machinery, as far as I understand, is what has been used for decades.

CHARLES TURNER (Glasgow, Scotland): Has any attempt been made to discover the effect of superheated steam? The reason why I ask is because I have treated solid coals containing high sulphur. I have had sulphur content as high as 5.2 per cent, and I have left a solid residue containing less than 5 per cent, and I have not had any cases of spontaneous combustion in the residue. I have not had any of the German coal, but I have had other briquettes and have never had this trouble with spontaneous combustion.

MR. SEIDENSCHNUR: The small amount of steam used in this gas residue decreases the sulphur content just the same as pure steam itself does. I pointed out that the sulphates left under one special condition may cause spontaneous combustion. They do accelerate it, but it is due partly also to the surface of the coke and the coke substance itself. It is just a coke substance which is easily ignited, and unless due care is taken, it will ignite, so sulphate chiefly acts as an accelerator. Even if the sulphates are not present, it will ignite nevertheless.

MR. TURNER: At what temperature?

MR. SEIDENSCHNUR: Even if the coke is cold, it will ignite. It will heat itself up slowly to 140° which is the ignition point. A small amount of oxygen, in the form of air, in about 50° to 60°C. will eliminate that danger. After the coke has been pushed out it carries waste gas containing some air until the coke has received a sufficient amount of oxygen, and afterwards it does not lend itself to spontaneous combustion.

MR. TURNER: It is sort of an inoculation process?

MR. SEIDENSCHNUR: That is right.

CHAIRMAN ANGLOCH: Are there any other questions that you would like to ask on the paper by Mr. Seidenschnur? If not, we will go on to the second paper, that by Dr. Rittman, on the manufacture of bituminous coal from petroleum. I am sure Dr. Rittman will be glad to answer any questions that might be asked.

F. C. GREENE (Old Ben Coal Corporation, Chicago, Ill.): I would like to ask Dr. Rittman, since he is manufacturing coal out of petroleum, if he ever considered putting a little more coal into the petroleum so as to help out the coal production.

What I see in the Doctor's paper, such as I gathered of it, he has a most excellent way of intruding binders into coal. Our West Virginia coals, frequently low volatile coals, have a habit of not taking very kindly to binders in the making of briquettes. There are processes which overcome some of the difficulties, notably the Dutch process, which is accomplished by kneading the screenings with the binder until it is thoroughly incorporated, and then is taken to the press.

It occurred to me that you might have something, if a persen had coal in the vicinity of low-grade bottoms which might solve that problem. I would be glad to hear of that.

May I also ask a question on Colonel Taylor's paper at the same time? I would like to ask Colonel Taylor if he has some figures, in a generalized way, of per ton day investment of charges.

J. W. E. TAYLOR: The Trumble process on a 1,000-ton basis can be installed for less than $400,000, and with the end process, the hydrogenation cracking and refining process in series it will cost a trifle more than $600,000.

MR. GREENE: $400,000 for 1,000-ton installation, $400 per ton. That is a safe figure?

COLONEL TAYLOR: That is up to the end of the basic process, but when installed in series, with the cracking process, the total cost runs about $200,000 more; about $600,000 will be a safe figure.

MR. GREENE: I think Colonel Taylor is to be congratulated upon approximating that desirable figure of $250 per ton-day, which I have persistently inquired about for every one of these carbonizing plants. It has been said that we would never go ahead on low temperature carbonization until the investment cost per unit had low capital charges, and it seemed that $200 was the desirable figure, and the $250 certainly would be attained. I congratulate the inventor, Mr. Trumble, upon getting $400 per ton day which I do not question in the slightest.

DR. RITTMAN: I believe that the procedure suggested by Mr. Greene is thoroughly feasible. At the present time in Kansas City we are experimenting in this direction.

MR. GREENE: We will be very glad to give you all the help we can with the coals that are difficult to bind, notably the low volatile Pocahontas coals.

The trouble seems to be that unless the binder is extremely well incorporated with the coal, you may press it, and then when it is discharged from the press it will open up right along the place where there is no binder. So if you have any pugging process or impregnating process it certainly would be of interest to the low volatile man in West Virginia, I am sure.

DR. RITTMAN: The way we propose to do that is where the fluid flows from the separator to run it through some simple mixers, and then just run a stream of finely broken-up coal into the mixer. That experiment is being eonducted by another party and I look for results.

MR. GREENE: If the other party permits I should be pleased to learn something more about it later on.

CHAIRMAN ANGLOCH: While Dr. Rittman is near the platform, are there any other questions anyone would like to ask him?

W. H. HILL (Koppers Company, Pittsburgh, Pa.): I should like to know what the softening point is.

DR. RITTMAN: A softening point is a flexible thing. In one industry it is one thing and in another, it is another thing. It all depends on the tests made. In one industry they measure it one way, and in another a radically different way, so that you cannot compare results, but by our method it is 300°—something above 300°F.

That is why I would not use it on a grate and that is also why I would break it up. The International Combustion Engineering Company indicate to us that they believe they will have no problem in breaking it up so as to burn and it will not have to be pulverized to the same degree as some other fuels because of the high volatile content which will tend to promote combustion and carry it on.

CHAIRMAN ANGLOCH: Are there any other questions for Dr. Rittman?

F. C. COLCORD (Colcord Coal Company, Montcoal, W. Va.): Would it act the same as cannel coal in burning or not?

DR. RITTMAN: First of all I have to confess that I do not know much about cannel coal. If you can enlighten me, I may be able to answer you.

MR. COLCORD: Cannel coal has an amorphous structure, like hard pitch would break, and an analysis usually of about 50 per cent volatile, and the ash on the purest I know of runs about 4 per cent up to 10 or 12 per cent. Cannel coal is in great demand for burning in open grates, and is in considerable demand for domestic fuel. It burns with a yellow flame.

DR. RITTMAN: No, I fear it would not, because of the point this gentleman brings up; it would melt under that high temperature. I fear it would not have the structure to hold up.

MR. TURNER: In the cannel coal the flame reducing material is for use where in Dr. Rittman's material it is oil. It becomes converted into oil by heat and does not exist in the cannel coal as oil.

DR. RITTMAN: I am sure it would not work in grates or in stoker, but it might if we mixed enough of this other material that Mr. Greene talks about. You do not know what might happen to it.

E. W. PARKER (Anthracite Bureau of Information, Philadelphia, Pa.): I would like to know whether the coal charged from the retorts is crushed before charging, the Stone Canyon coal for instance.

COLONEL TAYLOR: It is taken mine-run, and it comes out in the same sizes, with the exception of the fines which under certain temperature and pressure conditions will produce a mat. The fines can be made to come out in the form of the mat. The largest bodies, from nut size up, come out as stated.

MR. PARKER: Does the Stone Canyon coal have a tendency to coke in this retort?

COLONEL TAYLOR: No, you get true coalite.

MR. PARKER: What are the different sizes of commercial plants that could be built to utilize mine waste? I have reference to mines of this section of West Virginia where we take carbons which have to be thrown out and usually contain about 50 per cent of valuable fuels, and hand separation is not economical and mechanical separation is not desirable; therefore this process might be well applied providing the construction cost is not too big. I would like to know the approximate cost of one of these pilot plants.

COLONEL TAYLOR: To what particular size plant do you refer?

MR. PARKER: About 50 to 100 tons per day. I estimate a number of mines which have about 100 tons of waste material that must be disposed of.

COLONEL TAYLOR: To what point do you propose to carry the end processing?

MR. PARKER: In the first place, what would be the cost of carbonization without the final cracking process?

COLONEL TAYLOR: On a 50-ton basis I would say that it would cost you less than $600 a ton. It is assumed that you would install this at the mine where you have certain apparatus, and you would not start from the ground up with

your construction work. If you constructed an entirely new plant, it would cost you probably $750, but if you are installing it as an adjunct to a present going operation, the cost ought not to exceed $600 a ton up to the end of the carbonization cycle.

MR. PARKER: What would the opening cost?

COLONEL TAYLOR: That I cannot give you. You will have to get those figures from 610 South Broadway, Los Angeles.

V. G. LEACH (Peabody Coal Company, Chicago, Ill.): I would like to raise a point as to the ideal location for one of the plants. Would it not be more practical to locate the plant in a large city like Chicago than at the mine itself, having in mind that freight rates are not so favorable on coke as they would be on the coal, also being near a more suitable center of labor, and the mine field not being ideal for that type of work?

I would like to ask another question. I believe you mentioned that a certain coal that you term as worthless for steam use, ran 4 per cent in sulphur by volume. That is a very unusual method of determining or specifying sulphur, in the coal trade at least. I would like to know if you really meant 4 per cent by volume or by weight.

COLONEL TAYLOR: By weight.

MR. LEACH: I would also like to state that at least in the Middle West 4 per cent sulphur coal is not considered worthless as steam fuel by any means.

COLONEL TAYLOR: I will answer the last question first. I probably used the expression "volume" because I was dealing with volume at that time. This particular coal, in Stone Canyon, is worthless as a grate fuel on account of its tendency to mat and form a compound which resembles slag. The peculiar form of the sulphur content seems to be responsible for that condition.

The mines were opened up some years ago and probably more than one million dollars were spent in building a railroad and opening up the situation without making the necessary predetermination as to the usability of the coal as a fuel. The entire operation was a complete loss after they had spent more than a million dollars.

In answering the next question, as to the location for a low temperature carbonization process, I shall use a concrete illustration which is large enough to indicate what you really mean.

Some three years ago, the Southern California Edison Company was confronted with the necessity of installing 500,000 horsepower, additional steam plant. The electricity situation in Southern California, I will explain, is peculiar in that they must carry an approximately equal horsepower of steam and hydro.

I discussed with their executive engineer the matter of the location of a low temperature carbonization or distillation process, in order to convert the Western coals to usable condition as a grate coal, after removal of commercial

by-products. That is, those low-grade cheap coals which were easily accessible. Understand, please, that this process was not installed, nor is it contemplated to install any type of a by-product process, until the cost of oil reaches a place where it is warranted, the whole thing being figured on cost per kilowatt hour basis.

We determined, on the basis of careful economic research and competition factors, that the carbonization plant should be built at the steam plant in the center of population. That, I think, answers the query.

MR. TURNER: I understood Colonel Taylor to say that the plant does not need modifying in particular in order that it may treat any particular material. We have in England a coal which has the unfortunate habit of falling into slack within three days of raising to the soil. Would this plant treat such a coal?

COLONEL TAYLOR: Yes, we have treated finely broken coal by adjusting the temperature and pressure and the time cycle combination, which produces the mat, which we would have had to break up. This process has not been installed nor has it been used, so far, in combination with briquetting, but we find that, by adjusting our time cycle and temperature pressure, we can mat the coal. This by way of being a negative demonstration, or proof, of flexibility of process control.

We have found some coals that are high in foreign matter, such as dirt and slate, and which seems to prevent matting. We have found some shales which will not mat. However, there may be a place somewhere in the cycle which would mat these items or which would not mat them, as the case might be, but it happens that we passed them somewhere in our long series of experimental tests.

When I made the statement that that process requires no mechanical change for handling various materials, I was referring at that time, however, more especially to utilizing the waste from the lumber and logging industry, without changing over from the methods required in the treatment of coals.

It is entirely possible, and altogether probable, that you have coal—I was somewhat familiar with the coals of your country—which would not lend itself to the development of the point of maximum economy in the treating by this process, the same as any process might have some particular and difficult problem. I think that answers your question, does it not?

CHARLES S. COLLIER (DuPont de Nemours & Company, Wilmington, Del.): Would you think it possible to treat Dr. Rittman's coal if broken and put into the retort?

COLONEL TAYLOR: It requires some experimental work.

MR. TURNER: I think so, too.

COLONEL TAYLOR: You spoke of Dr. Rittman? I beg your pardon. I was thinking of the other Doctor who immediately preceded Dr. Rittman, and who

discussed certain German processes. No, you could not use it, not with this process. Dr. Rittman's liquid residue would be pretty hard to handle.

CARL SCHOLZ (Consulting Engineer, Charleston, W. Va.): In using bituminous coal what would be the gas analysis coming from the last retort, approximately?

COLONEL TAYLOR: It would depend entirely upon the analysis of the coal. I can give you some sample gas analyses which I have here. We will take up the first bituminous coal I come to; here is a Manchurian coal—the gas analysis on that in this particular test shows a carbon dioxide of 21.6, unsaturate 7.3, oxygen 3.4, hydrogen 11.0, carbon monoxide 9.1, methane 37.4, ethane 9.3, nitrogen 0, air 0.9.

Now the same coal when pretreated by hydrogenation—that was a non-hydrogenated coal that I quoted—in the proportion of two and one-half cubic feet to one pound of coal, produced the following gas analysis: carbon dioxide 10.8, unsaturate 2.2, oxygen 1.0, hydrogen 65.5, carbon monoxide 0.2, methane 13.7, ethane 5.6, nitrogen 0, and air 1.0.

That is from the first bituminous analysis sheet picked up at random.

G. W. WALLACE (Hillman Coal & Coke Company, Pittsburgh, Pa.). I would like to ask Colonel Taylor if I understood him correctly to say that all of his oil as produced was condensed with the condensation of steam, and if the steam, after the oil is condensed, is then superheated, and I would like to know the ignition boiling point, that is from the steam, and the percentage of oil that is carried over with the steam into the second superheater.

COLONEL TAYLOR: I can answer that question by saying "no" to the first portion. I did not make the statement that all of the oil was clear. Certainly we clear all of the free oil. There is, however, a certain amount of oil which has condensed during the cycle, and which passes into the next superheater, where it is then in turn vaporized again.

The relative percentage, as I stated from the technical detail, is all worked out in the form of graphs for all the different types of material and are available, but I do not have them with me. Mr. G. J. Hammond, at 610 South Broadway, Los Angeles, California, will send any specific graphs or any specific chart which anyone may want, covering any detail of the operation.

Is that sufficient for you?

MR. WALLACE: Not quite. What is the temperature of the steam that you must use when it enters the second superheater?

COLONEL TAYLOR: That is a point which I overlooked on the cycle chart. You will observe a low range and a high range. The high range is the carbonization temperature. The low range is the temperature which we predetermined by pilot plant practice in preparing to treat any given form of material, and the variation in temperature in any retort, as you pass from one retort to the other, is directly proportional for any type of material after its minimum and

maximum range has been determined. There will be about a 10 per cent drop between retorts, that is between batteries. The final retort in a six-battery plant, being zero, I figure 8 per cent to be proportional all the way through, after the minimum and maximum temperatures have been determined.

However, the only way in which we can get that information is by predetermination. Given any particular material on which to operate a plant, we predetermine the minimum temperature for retorting, and the maximum or carbonization temperature, which is the highest temperature we maintain. For instance, on the Manchurian coals our top temperature was 930°. On the Stone Canyon coal we were compelled to maintain a temperature running around 1,060 as the end temperature. The ignition, or the bottom line temperature, on the Manchurian coal was around 435 to 460.

MR. WALLACE: I do not believe Colonel Taylor understood my question. There is a superheat temperature in the first retort. Then you have a certain amount of distillation, and then you have a certain amount of carbonization where you drop certain quantities of oil. What temperature does that steam drop to before you resuperheat it?

COLONEL TAYLOR: It drops to 435 in the cycle.

MR. WALLACE: The point I was getting at was the type of oil that will condense and the type of oil that will carry on the second superheat.

COLONEL TAYLOR: No, there is no definite cracking prior to the end series where it will crack.

MR. TURNER: Supplementing the last speaker's question, what is the velocity of the steam?

COLONEL TAYLOR: I cannot give you that because I have not the charts here. I could only guess at it. It is an important element and you will have to send for it.

MR. TURNER: At that temperature, 435°F., there must be oil in the form of mist in the steam, and that must of necessity be carried through into the next superheater.

COLONEL TAYLOR: There is always a certain amount which goes all the way through the cycle until it is picked up.

MR. TURNER: Then there will be cracking in the second superheater.

COLONEL TAYLOR: There is no cracking within the process itself.

C. J. LYNCH (Palmerton): This is not directly related to carbonization process, but you mentioned the Stone Canyon coal as flowing freely, and you mentioned the relation to the sulphur content. I was wondering what is known

by anyone present. I thought maybe Mr. Turner might contribute something here as to the relationship between the free flowing quality of the coal upon heating to its sulphur content.

Our particular experience has been in the way of finding very free flowing coking coal upon heating will flow very freely into mesh and swell, and so forth. We really want that but in going over West Virginia and Pennsylvania coals, quite a few of them, in fact almost all that we found having a high sulphur content, were almost invariably the ones that were the most free flowing. I mean 2 and 3 or 3.5 per cent. Of course, some high sulphur coals do not flow, but the ones that do flow almost invariably have a high sulphur content.

MR. TURNER: I think that is peculiar because the lower mountain line of coals melt at a temperature of 350 degrees into consistency akin to treatment at atmospheric temperatures. That has a sulphur content of 0.71. I do not know that there is any relationship between the sulphur content and the flowing or the melting point of coal.

THE "K. S. G." LOW-TEMPERATURE CARBONIZATION PLANT AT NEW BRUNSWICK, NEW JERSEY[1]

By Dr. R. P. Soule

Chief Technologist, International Coal Carbonization Company, New York

There is now approaching completion near New Brunswick, N. J., a carbonization plant, the interest in which is quite out of proportion to its size. Compared with existing batteries of by-product coke-ovens, its rated capacity of 650 tons per day is not impressive. Yet this new project has attracted an unusual amount of attention for two reasons: first, it will be by far the largest plant in the world carbonizing coal at low temperatures, and secondly, it will commence operations early next spring under conditions unexcelled in their promise of commercial success by previous developments of this type.

The history of low-temperature carbonization in this country up to the present time has not been a happy one. It may be conservatively estimated that at least thirty million dollars have been spent by various organizations in fruitless attempts to promote a successful process. This record is indeed depressing unless a full appreciation exists of the reasons for this unfortunate situation. These reasons are of direct interest in connection with the new "K. S. G." plant, since the attempt is here made, for what is believed to be the first time, to capitalize to the fullest extent the commercial possibilities latent in carbonization at low temperatures.

It has never been contended by anyone familiar with the art that high-temperature carbonization is doomed to become obsolete. Low-temperature carbonization, far from being a solution of present-day coking problems, whether technical or commercial, as many of its early enthusiasts claimed, has a number of clearly defined limitations. Only in certain favorable situations is it superior to existing practice. It is because of failure to recognize these limitations and blind attempts at promotion of unsound processes under adverse conditions that their advocates so often have been disappointed.

An outstanding characteristic of low-temperature carbonization is

[1] The original paper was illustrated by 24 slides and a reel of motion pictures.

that no single product predominates in commercial importance to the extent that the other products can be sacrificed in its interest. The project which will enjoy the greatest promise of success, hence, is that in which equal consideration is paid to all the major products, the semi-coke, the gas, and the tar.

The semi-coke is, however, the most important product in point of weight, and it is obvious that the economics of the operation will be more sensitive to the credit obtained for it than for either the gas or the tar. The highest priced coke market is that of domestic fuel. In this connection it is unnecessary to dwell on the merits of semi-coke. It is very rare that a low-temperature carbonization undertaking has failed because of any shortcoming of the semi-coke as a domestic fuel. The question of selling price, however, is a different matter. This depends to a very great extent upon the nature of competing fuels and the buying habits of the consuming public within easy shipping distance of the plant. In general, it seems safe to say that semi-coke will find its best market in this country as a domestic fuel along the northeastern seaboard among a population accustomed to burning smokeless fuels. This is the reason for the location in New Jersey of the first K. S. G. plant in this country.

The low-temperature coal gas is a potential credit that has rarely been realized in full. Too often the location of the plant at the mine mouth or some other point remote from a consuming center has left no recourse other than to use the gas for underfiring the retorts. Again, processes involving internal heating, under conditions resulting in the degradation of the calorific value of the gas, are of necessity limited to the fuel gas market. The "K. S. G." retort is externally heated, and produces an 800 B.t.u. gas, well above the minimum heating value required for city distribution. The manner in which this surplus heating value is capitalized is a distinctive feature of the New Brunswick plant. It is blended in approximately equal proportions with 300 B.t.u. blue gas, so that the mixed gas to be sold will amount to about 8,000 cubic feet per ton of coal carbonized, and will have a calorific value of 535 B.t.u. per cubic foot. The retorts will be underfired by producer gas made from semi-coke fines, so that the entire production of low-temperature coal gas will be available for sale. A contract has been closed with the Public Service Electric and Gas Company of New Jersey for a minimum of 3,000,000 cubic feet daily of the 535 B.t.u. gas. Since this mixed gas will be sold at a figure nearly double the cost of the blue gas, it is

apparent that the coal gas will prove a very profitable source of revenue. This guaranteed outlet for the gas was the factor determining the location of the plant near New Brunswick.

The final important credits in a low-temperature carbonization operation are the tar and the light oil, the production of which at the New Brunswick "K. S. G." plant is estimated to be respectively 15,000 and 1,800 gallons per day. The commercial value of low-temperature tar is a subject that has been so frequently debated that it is not necessary at this time to say more than that the F. J. Lewis Manufacturing Company of Newark, New Jersey, has contracted for the entire production at a figure in excess of the current market for high-temperature tar. Not so much has been said, on the other hand, on the subject of low-temperature light oil. New refining methods are now available making it unnecessary to tolerate the excessive losses resulting from the conventional acid treatment. The refined product has been found to have 50 per cent greater anti-knock value than pure motor benzol. Here again is a credit that often has been overlooked.

It is not enough, however, that a process be designed to yield products of maximum value or that in addition the plant be best located to take advantage of these values. The processing or conversion costs must, of course, be kept low, or the high revenue will be wiped out by disproportionately high operating and maintenance expense. This is the rock upon which has foundered many an otherwise promising enterprise.

The heart and soul of any carbonizing process is, of course, the retort or oven. Not only must it have a high capacity per dollar of investment and be rugged of construction, but it must also be correct functionally. This last factor is extremely important. Granted that the design may be mechanically correct, if it involves excessive destruction of the tar, if it is limited to coal of one particular sort, such as a specially sized coal or a non-coking coal, or if it produces a very large percentage of breeze, then a prohibitive price may have to be paid for this mechanical perfection. Extreme simplicity of retort design, for example, is not in itself desirable if for the manufacture of a domestic lump fuel it imposes upon the operation the added steps of briquetting and perhaps recarbonization. It will be recognized, therefore, that there are many factors affecting the economics of low-temperature carbonization, and commercial success can be anticipated only when the right process is installed in the right place.

As a practical demonstration of these principles, the "K. S. G." plant now in operation at Karnap, near Essen, Germany, is one of the very few projects carbonizing bituminous coal at low temperatures which has a consistent record of profits behind it. In this single-retort plant, which was first put into service in 1924 and which has been in almost continuous operation since 1926, more than 50,000 tons of coal have been carbonized and a very considerable fund of experience accumulated. The general design of the German retort has been closely followed in the New Brunswick installation, but the plant as a whole has been considerably modified to conform with American engineering practice.

Figure 1 shows a sectional elevation of the retort. It has a rated capacity of 80 tons of coal per day, but it is believed that this rating is conservative, as the Essen plant at times has reached a throughput of 100 tons per day. The New Brunswick plant comprises eight of these retorts. It operates on coking bituminous coal of cheap slack size, and in a single operation produces lumpy semi-coke or char. The percentage of fines too small for sale as a domestic fuel is about 20 per cent in the German operation.

The retort consists of two concentric drums, externally heated, inclined slightly from the horizontal, and rotated at three-quarters of a revolution per minute on the bull-rings at each end. The outer drum is 72 feet long with a 10-foot diameter, while the inner drum is 85 feet long with a 5½-foot diameter. The raw coal is fed continuously from the storage bin into the retort through a screw conveyor. It is carried by the helical flanges in the inner drum to the upper end, where it spills through open ports into the outer drum. Upon gravitating to the lower end of the retort, it is picked up as semi-coke by a series of scoops, dropped on to a receiving plate and carried by the reverse helical flanges to the discharge gate. The total time the fuel is in the retort is about two hours. The coal gas escapes through the drum head and the off-take pipe at the upper end of the retort.

The question at once arises, why the double drum arrangement? The experience which the Stinnes engineers had with the single drum prior to the development of the "K. S. G." type of retort indicated that with a coking coal difficulties were encountered during its transition through the plastic stage. Carbon adhered to and built up on the inner walls. There was the further tendency, moreover, for the lumps of semi-coke to become excessively large and plug the discharge mechanism.

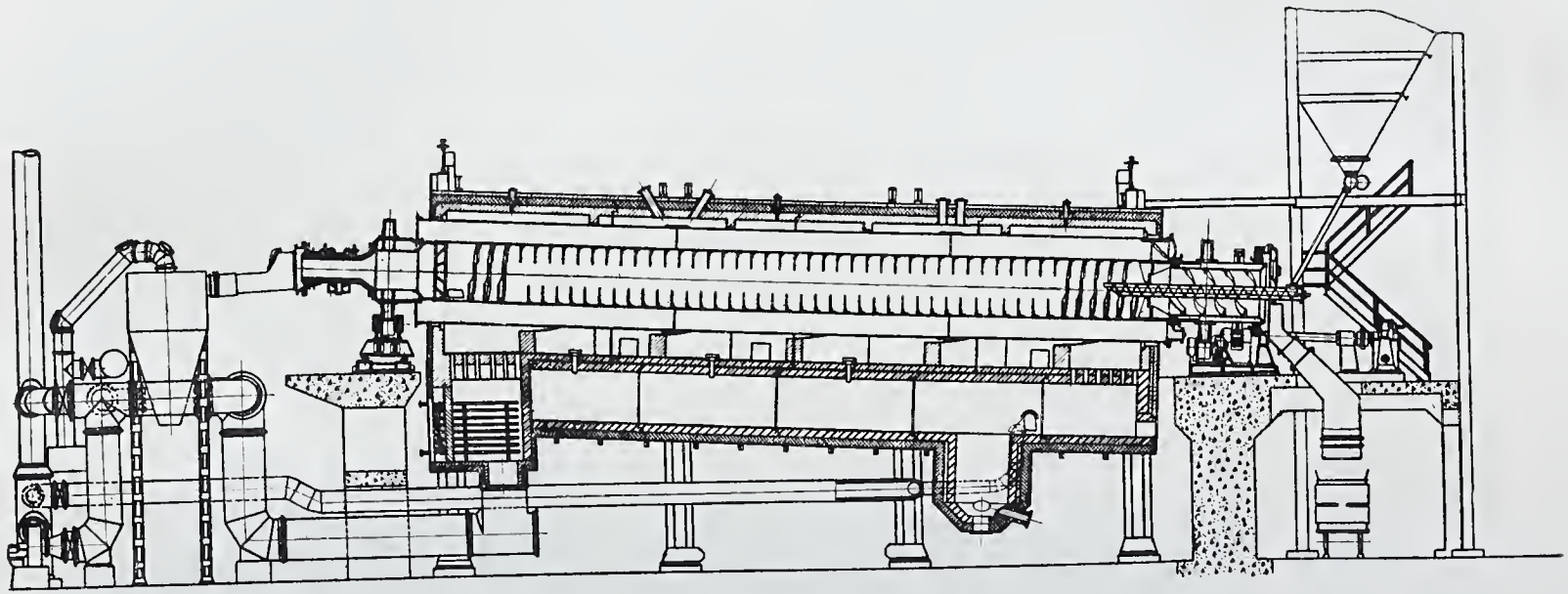


Fig. 1

The major innovation introduced to overcome these difficulties is the double drum arrangement. The principle involved is that of reducing to a minimum the period of time that the fuel is in the plastic state. The coal during its passage through the inner drum is dried and heated to a point below its softening temperature. It is then plunged into the upper end of the outer retort, where the highest temperatures are maintained. Each individual coal particle is thus almost immediately "case-hardened," so to speak, with a layer of non-sticky semi-coke, so that its agglomerating properties are correspondingly reduced. While the heating system is not of the popular counter-current type, it will be seen later that ample provision has been made to recuperate the heat in the stack gases.

The second means taken to prevent carbon deposits on the walls is the introduction of steam through a series of steam chests. There are eight of these chests extending along the inner wall of the outer drum for the upper third of its length, but by means of an automatic valve the steam is admitted only through those which are actually under the fuel bed. The direction of the steam is tangential, so that a screen of vapor is continuously interposed between the fuel and the retort walls. As a final precaution, a number of chains are stretched longitudinally in the upper end of the outer retort, so that any adhering carbon is scraped off. This method of dealing with a coking coal has been so successful that the "K. S. G." retort near Essen has never has to be taken out of service for cleaning.

The problem in heating the retort is to obtain variable temperature control and a high thermal efficiency. Moreover, since the retort is made of steel, it is necessary to maintain a neutral atmosphere to prevent oxidation. As mentioned above, the cheapest possible gaseous fuel is used, which is hot producer gas made from the semi-coke fines. This is generated in a central producer gas plant, but each retort has an independent heating system. The gas is burned in a combustion chamber, where gas and air are admitted through two proportioning burners in exact combining ratio. Consequently a temperature of about 2,500°F. is obtained at this point, which is considerably higher than that desired in the retort flues. Rather than use excess air for cooling, with resultant loss of thermal efficiency and oxidation of the retort, the stack gas recirculation system is employed. In this system a circulating fan takes a portion of the flue gases from the base of the stack, mixes it with some of the hot gases from the combustion chamber and forces it into the first pass

at the lower end of the retort setting, where a temperature of about 1,200°F. is maintained. The flow of this mixed heating gas is baffled to make it take a helical course around the retort. The heat abstracted from it by the carbonizing coal is replaced by introducing hot combustion chamber gas into each pass through ports connecting with a central flue running longitudinally under the retort. The dampers in these ports are so arranged that increasingly higher temperatures are maintained in each pass, reaching 1,350°F. in the uppermost pass surrounding that part of the retort where the coal falls from the inner to the outer drum.

The hot gases leaving the retort setting pass directly into the steam superheater, thence through the jacket around the dust-catcher, (which is heated to prevent condensation of tar), and into the stack. The superheater is a nest of alloy steel tubes. From 100 to 200 pounds of exhaust steam per ton of coal are raised by the superheater to a temperature of 900°F. Since this steam leaves the retort at almost the same temperature, it does not contribute to the heat of carbonization. Its function is both to prevent carbon formation on the retort walls and to prevent excessive cracking of the tar vapor. The gross heat of carbonization is about 800 B.t.u. per pound.

The coal gas, tar vapor, and steam leaving the retort pass first through a dust-catcher. The amount of dust collected is less than 0.1 per cent of the coal processed and no difficulty is experienced with emulsions, dehydration being satisfactorily accomplished by simple settling. The pressure in the retorts is maintained constant by an automatic control system, acting through dampers in each of the coal gas off-take lines and the governor of the exhauster.

Figure 2 shows a retort assembled for shipment. Its weight is about 160 tons. The outer drum is made of open-hearth steel in three sections. The end sections are of $\frac{7}{8}$-inch plate, while the middle section is of 1-inch plate. All longitudinal and circumferential seams are hammer-welded with water gas and annealed. The circumferential seams are reinforced with welded bands 2 feet wide and $\frac{13}{16}$-inch thick. The inner drum, having a smaller section, is made of $1\frac{3}{16}$-inch plate. It also is made in three sections with all seams hammer-welded with water gas. The reinforcing bands at the circumferential seams, however, are both riveted and welded.

In Figure 2 the retort is viewed from what is its lower end in operating position. The coal feed conveyor pipe can be seen at the center of the end plate, with the coke discharge chute directly be-

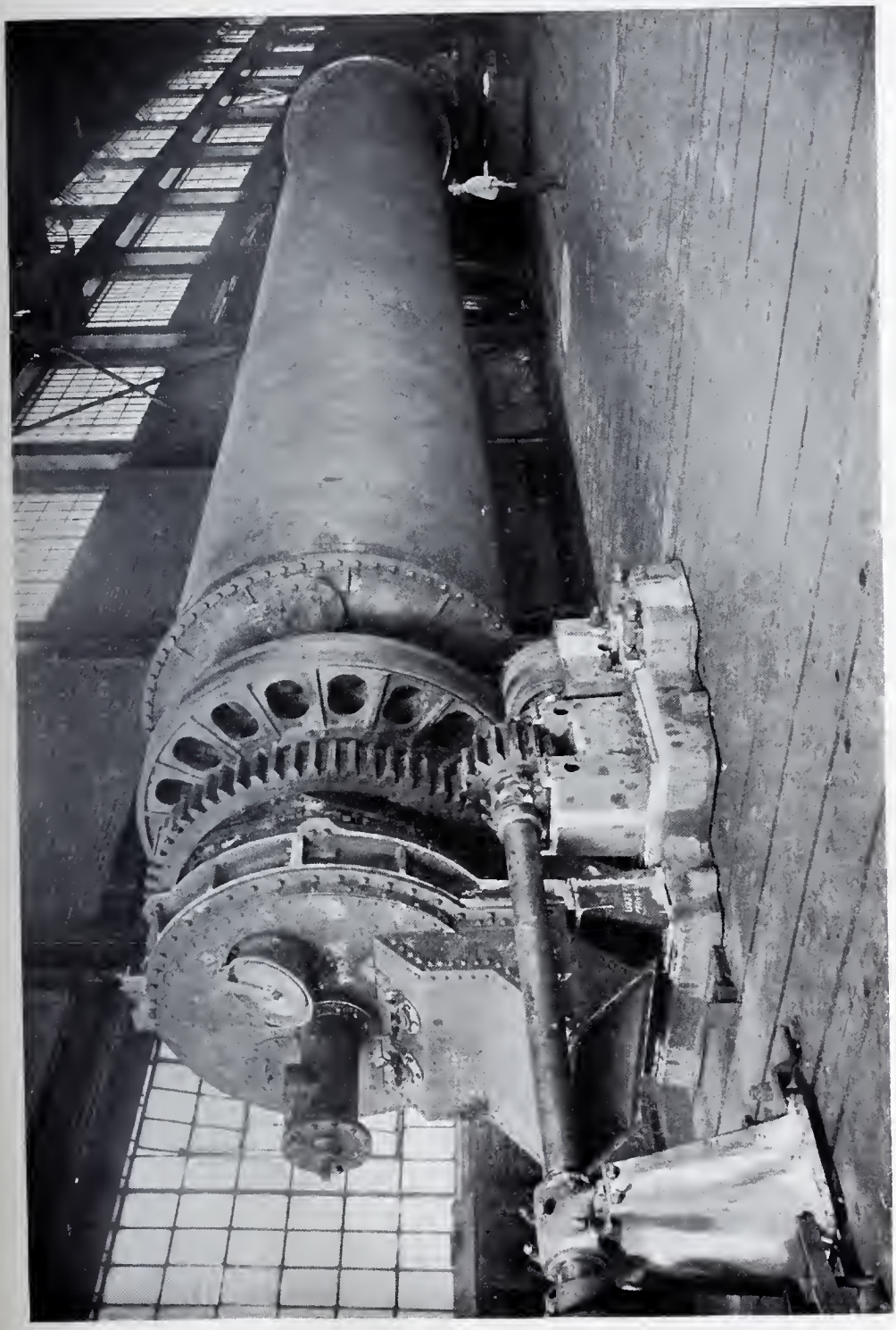


FIG. 2

neath it. The bull-ring is carried on wheels that are flanged only on the upper side. The downward thrust of the retort is taken by thrust wheels (not shown), which turn on vertical axes and bear against the side of the bull-ring. The construction of the gear wheel will be seen to be non-rigid to compensate for any slight longitudinal distortion of the retort. Thus, the center line of the gear-wheel can move relatively to the center line of the drum, and any tendency toward binding of the driving pinion is eliminated.

The lower end of the retort is the fixed end, and its expansion is upward. Under average working conditions, the total expansion of the outer drum is about 6 inches and that of the inner drum about 3 inches. The expansion of the inner drum is taken by rolls supporting the wheels carrying the upper bull-wheel. The 3-inch differential between the outer and inner drums is allowed for by a stuffing box, which permits the outer drum to slide over the inner drum. Allowance is also made by a stuffing box for the movement of the gas off-take pipe inside of the fixed pipe leading to the dust-catcher.

Figure 3 is an end-view of the retort house of the New Brunswick plant in an early stage of construction. It comprises a battery of eight retorts. Each retort is surrounded by a steel casing lined with insulating and fire brick. This view shows the lower end of the setting, where the coal is charged and the semi-coke discharged. Coal is fed from each of the eight hoppers by a variable-speed star feeder into the screw conveyor that leads into the retort. The semi-coke is continuously discharged from each retort into a small hopper, which is intermittently emptied into cars running on a track lengthwise of the retort house to the coke quencher.

Figure 4 shows the lower half of a retort setting, ready for the drum to be lowered into place and the brick arch over it to be completed. It will be seen that the baffle walls are designed to make the heating gases follow a helical path around the drum. The central flue running lengthwise of the setting, which communicates directly with the combustion chamber (see Fig. 1) and carries gas at about 2,500°F., is below the floor of Figure 4. In the foreground there can be seen one of the sliding brick dampers which control the admission of hot gas from this flue into the passes around the retort.

Figure 5 shows one of the retorts being lowered into place, with two others already in position. The retorts are shipped from the shop completely assembled and ready for erection in the field. Each

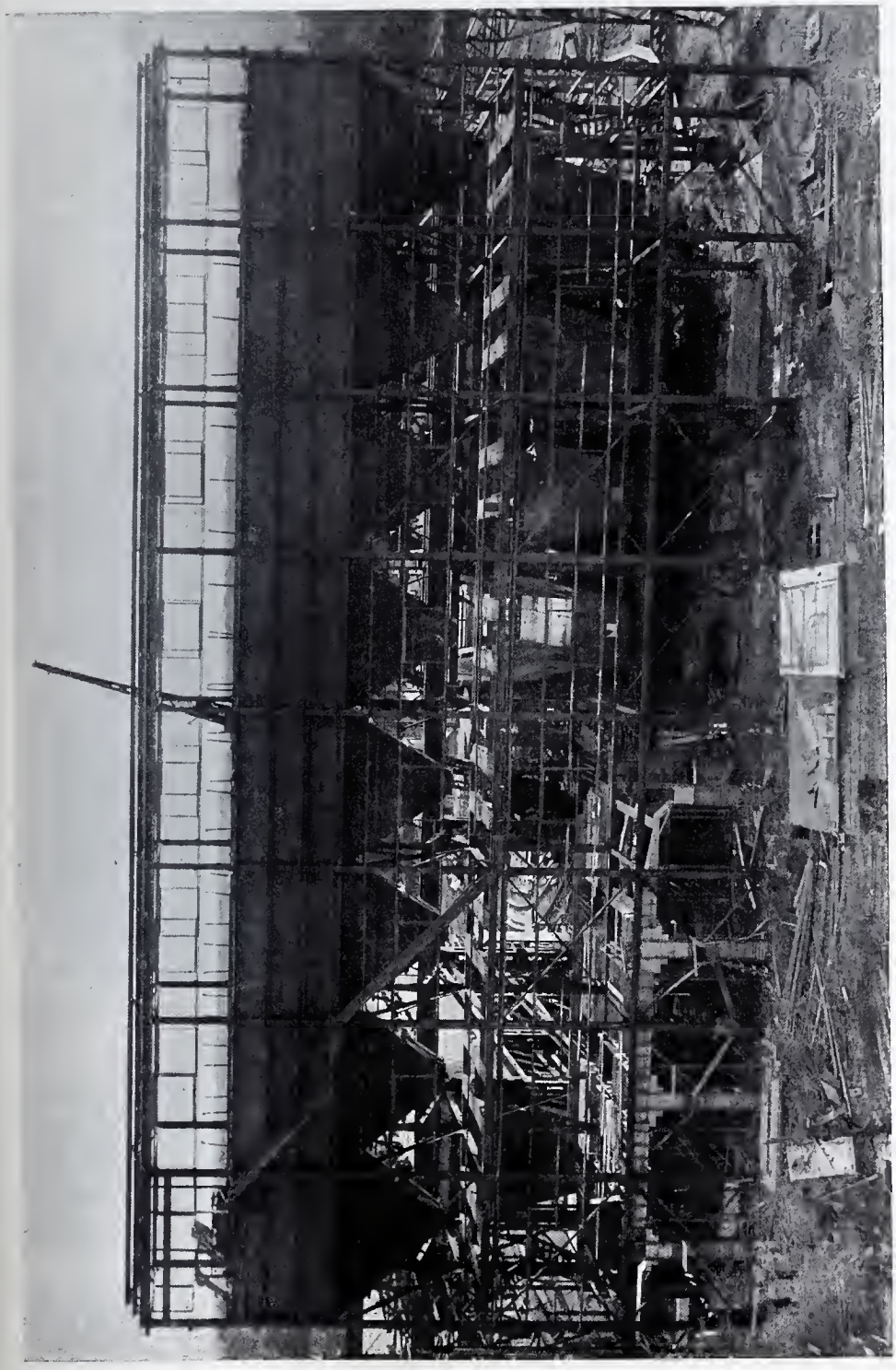


FIG. 3

retort requires three flat cars for shipment. The gantry crane shown in this figure runs on a track across the retort house and over a railroad siding. Thus, the crane has only to lift the assembled retort directly from the cars, move it to the proper place, and lower it into position.

In Figure 5 the retorts are viewed from the upper end. There can be seen the gas off-take pipes with the steam valves just behind them. Each steam valve is connected by eight flexible metal pipes to the steam chests in the outer drum.

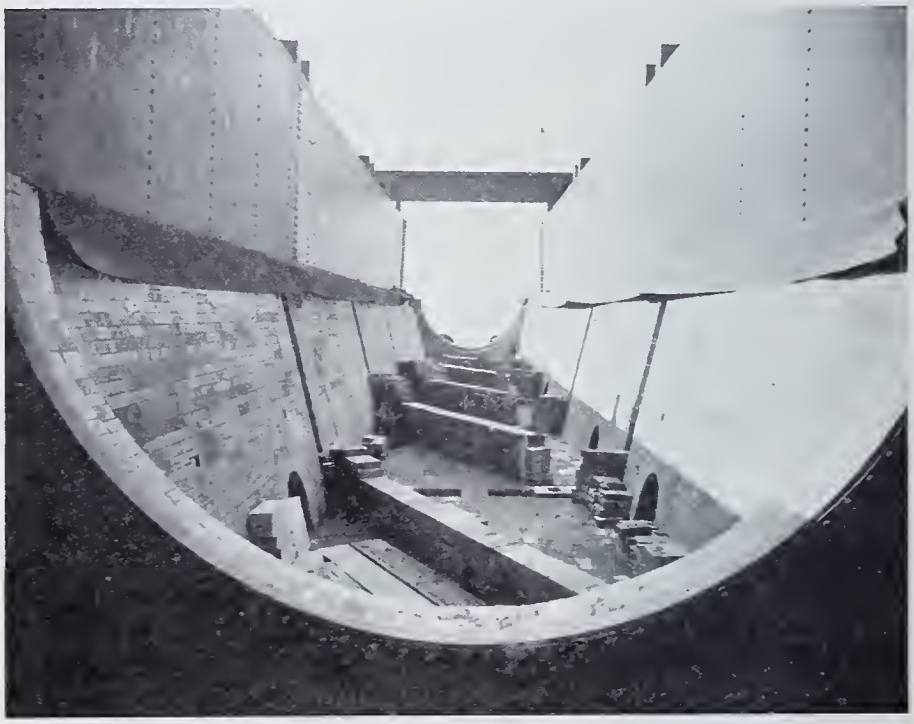


FIG. 4

Figure 6 is a panoramic view of the plant taken November 5, 1928. At the left is seen the retort house and in the center, the building housing the producers, the water-gas sets and the boilers. All units are built in duplicate, so that one spare is always available. There are two producers, equipped with rotating bottoms for automatic ash elimination and water-jacketed for waste-heat steam generation. The water-gas plant comprises two 11-foot generators, hand-clinkered, but automatically charged, with waste-heat boilers for the stack gases. While this plant will make only blue gas in regular

operation, each set is provided with a carburetor and superheater. Thus, in the event of any interruption in the operations of the retort house, the blue gas can be enriched by oil gas instead of coal gas.

The steam plant consists of two 500 h.p. boilers, operating at 200 pounds pressure and equipped with Coxe stokers to burn semi-coke breeze. Since both the producers and the blue-gas generators are nearly self-supporting so far as steam requirements are concerned, the main function of the boiler plant is to supply steam for motive power. Steam is used to drive the coal gas exhausters, the engines rotating

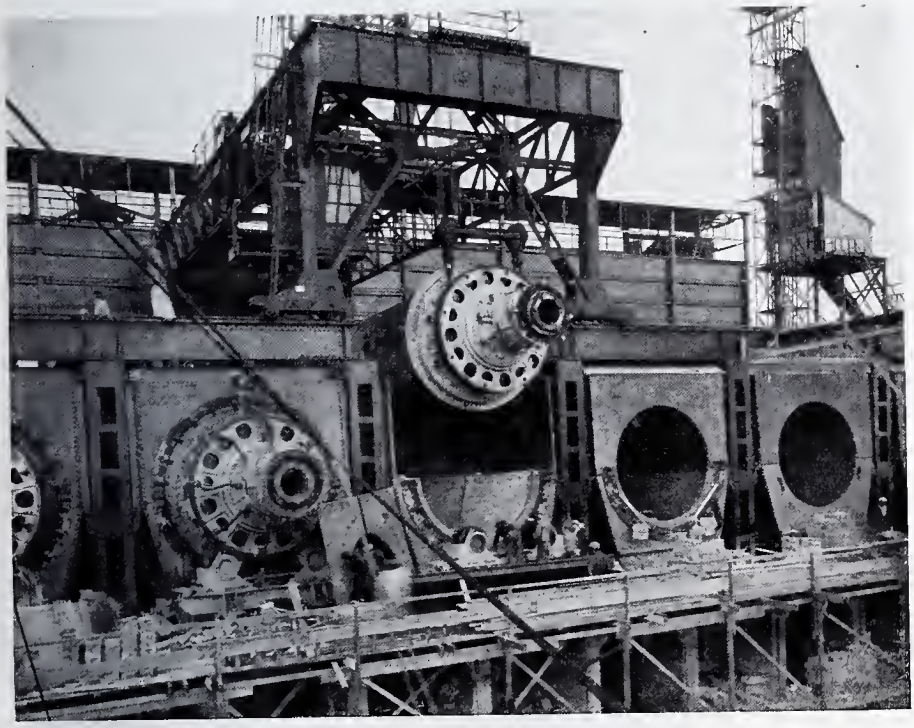


Fig. 5

the retorts, and the various tar and oil pumps. Compared with electric operation, not only is greater flexibility of speed thus made possible and greater assurance obtained of continuity of operation, but also exhaust steam is made available in quantity nearly sufficient to meet the requirements of the carbonizing process.

Figure 6 also gives a general view of the fuel-handling equipment. The coal is unloaded into a track hopper at the foot of the coke-screening house seen at the right in this picture. It is then carried by an inclined conveyor to the coal-screening house shown in front of

FIG. 6

the producer building. If mine-run coal is brought to the plant for retorting, the 2- to 5-inch size is here screened out for use as generator fuel. Any fuel purchased only for this purpose is, of course, screened to remove fines produced by breakage in transit. The coal under 2-inch and over 5-inch is combined and passed through a hammer mill, where it is crushed 95 per cent to pass $\frac{1}{8}$-inch and 100 per cent to pass $\frac{1}{4}$-inch. This crushed coal is carried to the retort house by an inclined conveyor.

The semi-coke quencher and the skip hoist serving it can be seen at the right of the retort building. The semi-coke from the hot cars is raised and discharged into the quencher, which is simply a container through which cold inert gases are circulated. The gases are cooled by water in a tower, seen lying on the ground in front of the quencher at the time this picture was taken. No attempt is made at New Brunswick to generate waste-heat steam, as in the usual application of dry-quenching to high-temperature coke. The operation justifies itself merely on the ground of thorough and uniform cooling of the semi-coke to less than 200°F., which is well under its ignition temperature, without having to resort to drastic water quenching and the resultant increase in the percentage of unsalable fine sizes.

An inclined conveyor, the unfinished open end of which can be seen near the center of Figure 6, carries the quenched semi-coke to the coke-screening house. Here the semi-coke is screened into the usual domestic sizes, $\frac{3}{4}$-inch being the smallest size to be offered for sale. Hoppers for three marketable grades are installed, with provision for discharging into either railroad cars or motor trucks. Of the semi-coke sizes smaller than $\frac{3}{4}$-inch, the $\frac{1}{4}$- to $\frac{3}{4}$-inch is used for producer fuel and the under $\frac{1}{4}$-inch for boiler fuel. It has been the experience at Essen that 80 per cent of the run-of-retort semi-coke is recovered in lumps larger than $\frac{3}{4}$-inch.

The gas purification equipment cannot be seen in Figure 6. The coal gas passes through a primary cooler of the indirect type to the exhauster, and thence through a scrubbing tower for removal of the light oil. The blue gas purification train consists of a primary cooler, a relief holder, and a secondary cooler. The coal gas and blue gas are then combined in an automatic proportioning valve and pass through sulphur purification boxes to the storage holder of the New Jersey Public Service Electric and Gas Company on an adjacent property.

The plant is scheduled to be in operation by March 1, 1929.

PRINCIPLES IN THE BRIQUETTING OF COKING AND NON-COKING BITUMINOUS COALS

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University of Alberta

Introduction

The briquetting investigation which forms the basis of this paper was begun in 1922 and is still in progress in the laboratories of the Scientific and Industrial Research Council of Alberta, at the University of Alberta, Edmonton, Canada. The work has been carried out by N. H. Atkinson, W. D. MacDonald, F. L. Grindley and W. A. Lang (the latter since 1924) under the general direction of Edgar Stansfield.

The authors have summarized the present knowledge of the art of briquetting, giving special emphasis to points which appear to have some element of novelty. They have omitted here the details of their experimental data, which might mask rather than reveal the fundamental results obtained.

In the process of briquetting, as commonly practiced in America, the coal or other raw material is dried, if wet, and then crushed, if necessary. The required amount of binder, either crushed or molten, is added and the mixture raised to a temperature sufficient to make the binder flow readily. The mass is mixed and kneaded together in mixers and fluxers of various types. These mixing devices are sometimes directly heated, but are usually steam heated externally; in most cases steam is also passed into the charge in the fluxer. The mixed mass is finally brought to a suitable temperature and sent to the press. From the press the hot and somewhat fragile briquettes are sent over an inclined screen to remove any fins, broken bits and other fines, which are sent back to the mixing train and repressed. The briquettes are then cooled and stored.

The finished briquettes should possess the following properties: they should be a suitable size and shape for convenient handling, without sharp corners or edges that are easily knocked off and of such form as to allow free passage of air through the furnace during

combustion. They should be strong, clean to handle, not too brittle and neither soft, friable nor easily abraded. They should be weatherproof, not affected by rain or frost, nor soften unduly when exposed to the summer sun. Finally they should form a good fuel—long flamed, short flamed or smokeless—according to the purpose for which they are required, holding their shape without softening or crumbling in the fire, not clinkering easily, of high calorific value and low ash content. These requirements are difficult to satisfy in their entirety without making the cost prohibitive.

The successful production of briquettes depends upon the equipment employed; the material briquetted, its chemical and physical properties; the binder used; and the procedure followed.

EQUIPMENT

Three types of mixers are commonly employed in commercial practice, viz., horizontal helical mixers, vertical or horizontal fluxers with revolving and stationary arms, and edge-runners or masticators. In many plants only the first two types are employed, in others all three. The mixing equipment available for this investigation consisted of two of these, a horizontal helical mixer and a vertical fluxer.

Three types of presses are in general use, viz., high pressure extrusion presses, plunger presses and roll presses. High pressure extrusion presses are used extensively in the briquetting of the self-binding lignites of Germany. Plunger presses were commonly designed for large briquettes. When the demand was made for small briquettes, a new design was necessary and plunger presses have been built to give a big output of small briquettes. More commonly roll presses are used for this purpose. Roll presses have two rolls, each with a large number of pockets formed on its face and with the rolls revolving against each other, in such a way that the pockets on the two rolls meet face to face as the rolls go round. This design permits a large production of small briquettes with low power requirement, and the briquettes can be made a good shape for handling and firing. A disadvantage, particularly for research purposes, is that there is no accurate means of regulating or determining the pressures. In this investigation a small experimental plunger press has been used for the major part of the work; comparative tests were made on a semi-commercial roll press.

The horizontal helical mixer used in these laboratories was made

by Joseph Baker & Sons & Perkins, Ltd., London, England. The mixing is done by two blades, one rotating at twice the speed and in

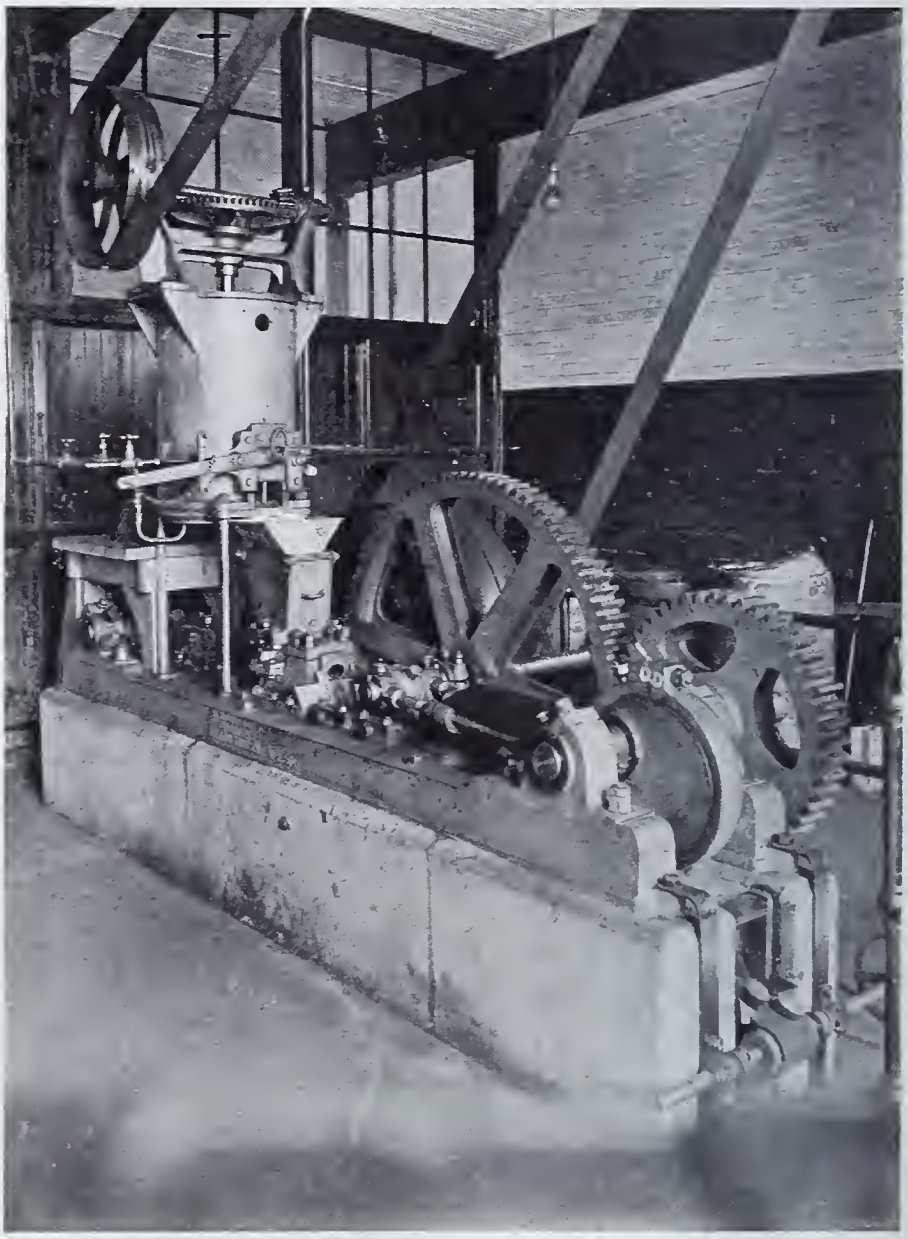

Fig. 1. Plunger Press

the opposite direction to the other. The mixer is steam-jacketted and steam can also be blown into the charge if desired. It can be

used to mix batches of 25 pounds or less, and be tipped to discharge its contents.

The vertical mixer or fluxer shown situated above the press in Figure 1, was also used at the beginning of the investigation. It also is steam-jacketted and provided with steam jets for blowing steam into the charge. The mixing is done by paddle arms carried on a vertical shaft. The mix can be discharged into the feed-hopper of the briquetting press by opening a side gate at the bottom of the fluxer. The use of this fluxer in the experiments was discontinued because as a batch mixer it was found that the temperature could not be controlled easily, and that the abrasion of the binder-coated particles in the fluxer created fresh surfaces which did not become coated with binder and thus reduced the quality of the briquette.

The plunger press (Fig. 1) is a small capacity, strongly-built machine, well suited for experimental work. It is of a horizontal, double-plunger type and is rated to give a pressure of two tons per square inch, or seven tons in all, upon the briquette. This pressure is exerted through, and is controlled by a spring. The briquettes are oval, $2\frac{1}{2}$ inches long and $1\frac{3}{4}$ inches across, but can be made of varying thickness, usually 1 to $1\frac{1}{2}$ inches on the face. The press as set up makes 25 briquettes a minute, and thus has an output of $4\frac{1}{2}$ pounds per minute when making 3 ounce briquettes. It is possible to regulate the feed, and therefore the size of the briquette; also the pressure exerted, and, to a slight extent, the duration of the pressure. Figure 2 shows in diagrammatic form four positions of the plungers during the cycle of making and ejecting a briquette.

Figure 3 shows the roll press used. It has two shell rolls 24 inches in diameter. Each roll has 3 rows of 42 pockets each, or a total of 126 pockets, and the rolls are driven at 9 to 10 revolutions per minute. It makes a pillow-shaped briquette of about 2 ounces weight, the weight depending on the density of the coal. That is, the press has a capacity of about 4 to $4\frac{1}{2}$ tons per hour. This press is a type largely used in commercial briquetting, but is a smaller size.

PROCEDURE

The coal is crushed to the desired size and its screen analysis determined with Tyler standard screens in a ro-tap shaking machine, or, a mixture of a desired screen analysis is prepared by first screening the crushed coal into the various sizes over Tyler standard screens on a small Marcus shaker screen and then mixing together the desired

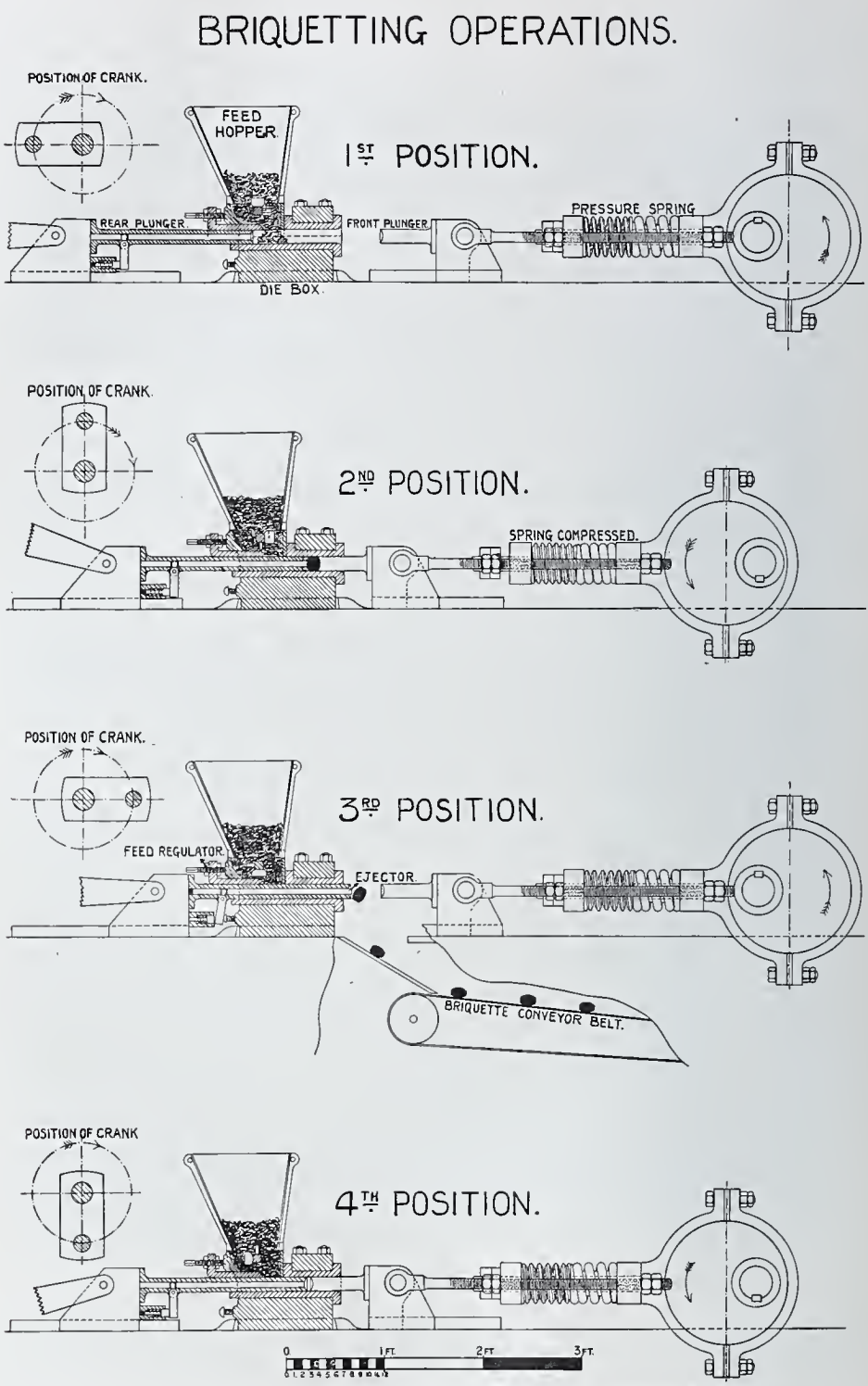

FIG. 2. DIAGRAM OF PLUNGER PRESS SHOWING FOUR POSITIONS OF PLUNGERS

weight of each size of coal. The weighed coal, usually 8 kgm. or about 18 pounds, is placed in the mixer, where it is mixed and heated,

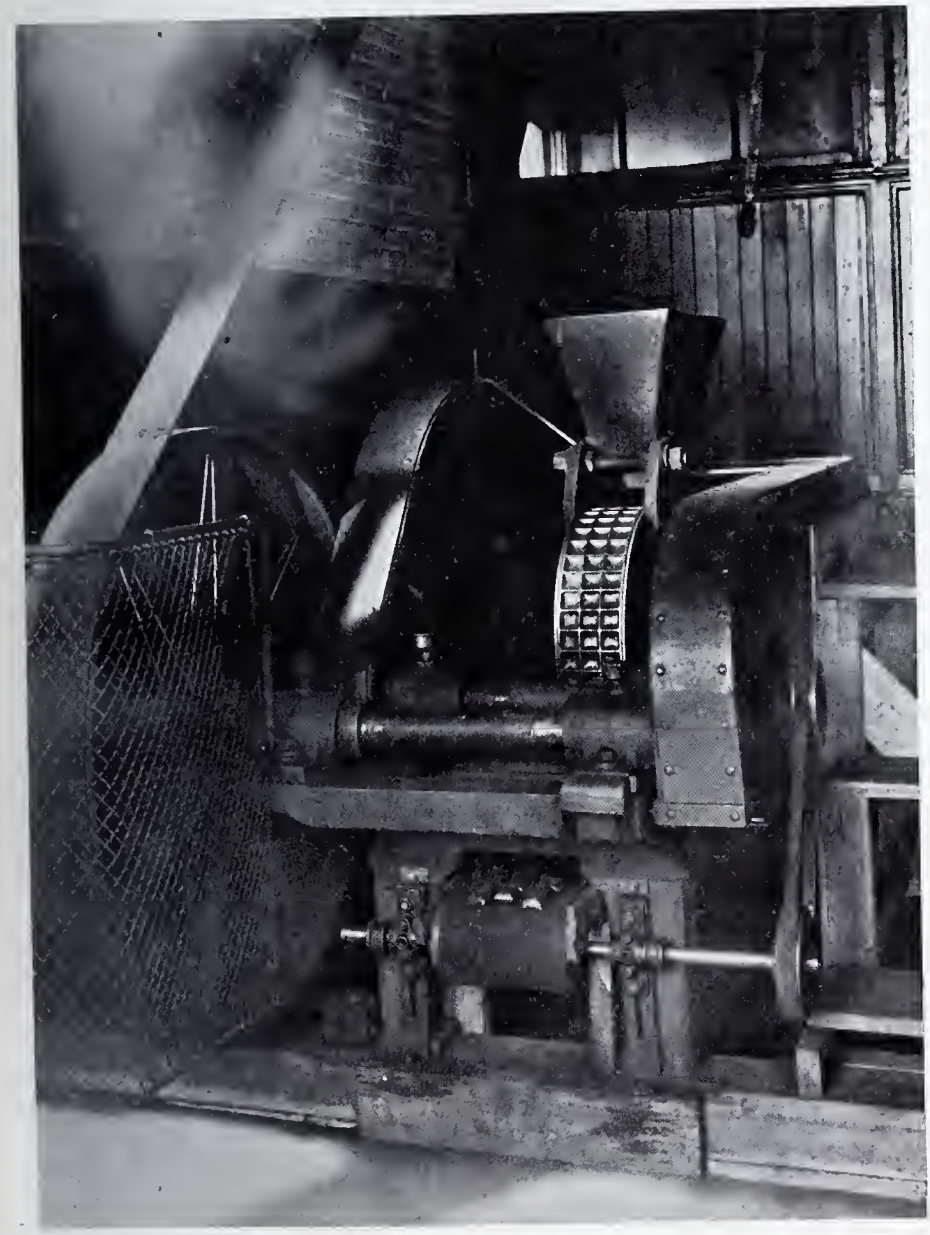

FIG. 3. ROLL PRESS

and the binder or binders then added in weighed amounts and in the order arranged. Weighed addition of water may also be added

at any desired stage of the procedure. Mixing is continued usually for two or three minutes and the temperature raised to the required degree as shown by a thermometer immersed in oil in a guard-tube which projects into the mixed mass. The charge is then dumped into a hot, water-jacketted receiver from which it is hand-fed to the press at the required rate.

Records are kept of the constituents taken, order of mixing, time of mixing, temperature at each stage (especially of the mix as it goes to the press). Any special points observed during mixing and the behavior of the mix in the press are also recorded. A sample of mix as it goes to the press is taken for moisture determination.

The amount of binder in any batch of briquettes is recorded as the parts by weight of the binder added to 100 parts by weight of coal. This is termed the "mixing ratio" (M. R.). The mixing ratio is therefore slightly higher than the percentage of binder in the briquette made. Additions of water and other constituents are also recorded on the same basis. This sytem is found to have many advantages.

The briquettes are classified by inspection, by their real and apparent specific gravity and porosity and by the rattler test.[1] Of these, the specific gravity and the rattler test appear to give the most satisfactory classification. Comparison of briquettes made from the same coal and same binder show that the quality of the briquette increases with the specific gravity, but this value cannot be used to compare briquettes made with different coals. The rattler test appears to give a very satisfactory criterion of the handling quality of the briquettes. Very soft briquettes may show a low rattler loss, and yet be worthless, but these exceptional cases can be ruled out by inspection. Briquettes are burned in a furnace to study their firing qualities, and heated in a closed retort to observe the amount of smoke they give off and the quality of coke they produce. In some cases a sample of briquettes is exposed to the weather for a few months and then tested in the rattler for comparison with the rattler results on the original briquettes. Briquettes are regarded as satisfactory when the tests indicate that they can be handled and

[1] The rattler test consists of placing about 2000 grams of briquettes in the drum, which is then revolved 200 times at 32 r.p.m. The rattler is a standard machine adopted by the American Society of Testing Materials for testing paving bricks. The drum is 25 inches long and 30 inches outside diameter and is built of cast-iron plates 6 inches wide, 25 inches long and $\frac{1}{4}$ inch apart. The material rubbed off the briquettes as they roll around falls out between the plates, and the per cent loss of weight is determined.

shipped without serious abrasion losses, will burn well in the fire without falling to pieces and can be stored exposed to weather without notable deterioration. A briquette, otherwise satisfactory, that does not lose more than 20 per cent in the rattler test is regarded as strong enough to be handled and shipped; but briquettes have been made which only lost 2 per cent.

Materials Briquetted

Materials commonly briquetted are the coal fines produced during mining and handling operations, as well as other small sized fuels—coke breeze, semi-coke from low temperature carbonization, lignite char, etc. Fine coking coals can more readily be utilized without briquetting than can those which do not coke. Carbonized materials are more difficult to briquette than are ordinary coals, and coke breeze in particular causes excessive wear of the machinery.

Chemical and Physical Properties of the Materials

Such properties which influence the briquetting of a coal are (1) moisture content (2) ash content (3) volatile content and coking character (4) resistance to wetting (5) hardness, friability, and porosity.

I. Moisture. High moisture coals are not satisfactory for briquettes unless first dried, because they disintegrate readily and will not stand firing or handling. When dried they become porous and therefore require more binder.

II. Ash Content. (Tests with Trent process.) Ash is undesirable in any coal but it is more so in coal to be briquetted as it wastes binder. The density of a coal increases with its ash content; and, for the same weight of coal the surface to be covered, and therefore the binder required, varies inversely as the density of the coal, other things being equal. It follows that 100 pounds of coal containing 20 per cent of mineral impurity would require less binder than would 100 pounds of coal containing only 5 per cent of impurity; but a mixture of 80 pounds of clean coal with 20 pounds of impurity would require notably more binder than would 80 pounds of clean coal mixed with only 5 pounds of impurity. In other words, a clean coal requires less binder than a dirty coal per ton of effective fuel.

If a clean sample and a dirty sample of the same coal are briquetted with the same proportion of binder, the dirty sample will often give the stronger briquette. The waste is indicated if the amount of

binder is expressed in terms of binder per ton of effective fuel. This is shown by Table I of results obtained with a sub-bituminous coal and an asphalt binder. Run 583 was made at a different time, but under closely comparable conditions.

TABLE I

RUN NUMBER	ASH	BINDER PER 100 POUNDS ACTUAL COAL	BINDER PER 100 POUNDS ASH-FREE COAL	RATTLER LOSS	SPECIFIC GRAVITY		VOIDS
					Apparent	Real	
	per cent	*pounds*	*pounds*	*per cent*			*per cent*
656	53.0	5	10.6	4.8	1.54	1.80	14.1
655	12.0	5	5.7	22.5	1.10	1.43	23.0
583	25.1	6	8.0	5.3	1.31	1.49	12.5

Careful examination of a briquette made with dirty coal will often show particles of dirt which are not coated with the binder. This fact suggested the possibility of cleaning the coal during briquetting, by means of a modification of the Trent process in which the binder is used instead of oil. In the Trent process fine coal is moistened with water, and a suitable oil or other liquid is added, with mixing, until a change of phase occurs. At this point the coal becomes moistened with the oil and the water is set free carrying with it much of the mineral impurity which is not wet by the oil. Experiments showed that if the mixing were done hot, 90° to 100°C., binder asphalt, or soft coal tar pitch, could be used instead of the ordinary liquid oil. However, the binder thus required was several times as much as that required for briquetting. One possibility is suggested: in ordinary coal cleaning processes the greatest difficulty is experienced with the dust. This dust can be separated and cleaned as above by the Trent process using the binder asphalt, and then the larger sized particles, separately cleaned if desired, added and the briquettes made in the usual way. This was tried, the particles through a 48 mesh screen being cleaned, but without cleaning of the larger particles, and the resulting briquettes were unusually good. This process, as with the ordinary Trent process, is not equally suited to all coals.

In some tests with two sub-bituminous coals ("low rank bituminous" in M. R. Campbell's classification) which are not readily amenable to this treatment, ash reductions ranging from 30 to 43 per cent were obtained. These results could be improved with better facilities for mixing and washing. When these uncleaned and

cleaned fines respectively were mixed with coarser coal and briquetted, the most notable difference was the lower percentage of voids in the briquettes made with the cleaned fines.

III. Volatile Matter Content and Coking Properties. The quantity and nature of the volatile matter in the coal affects the behavior of the briquette in the fire and the nature of the smoke given off. A coking coal will not only require less binder than a non-coking, other things being equal, but the briquettes will stand up much better in the fire. This disadvantage with non-coking coals can be partially overcome by the choice of a suitable binder or by the addition of some coking material.

IV. Resistance to Wetting. Sub-bituminous and lignitic coals wet easily with water; semi-bituminous wet less readily, while bituminous coals are difficult to wet. No specific study has been made of this property, but it has been studied indirectly in other connections and the indications are that this factor is important in determining the effect of moisture during briquetting.

V. Hardness, Friability and Porosity. A hard coal does not crush easily during mixing and pressing. The hardness of the particles also gives strength to the finished briquettes, although hard abrasive materials may cause serious wear of the machinery. A porous, friable material necessitates the use of an increased amount of binder. No satisfactory method has yet been devised for measuring the absorption of the binder into the pores of the coal.

The amount a coal will crush during mixing and pressing must be considered in deciding the original sizing of the coal best suited for briquetting. The sizing of the coal has a large effect on the quantity of binder required. Two main points are involved, first the area to be coated with binder, and second the voids to be filled. The area to be coated increases extremely rapidly as the size of the particle is decreased; but, on the other hand, as has been worked out in connection with concrete, the voids to be filled are reduced by a suitable proportioning of the different sizes. A serious complication is introduced on account of the crushing which goes on during the mixing and pressing operations. If, after all or most of the particles are coated with binder, crushing occurs fresh surfaces are produced which may not get coated and will be a source of weakness in the final briquette. Experiments corroborate these theories as shown below.

References to colloidal coal as a briquette binder occurred in the technical journals of 1926. Experiments were made to ascertain if

finely ground coal mixed with asphalt could be pulverized and used as a binder. Five parts of asphalt mixed with 100 parts of coking, bituminous coal, crushed as usual, gave good briquettes; 40 parts of asphalt mixed with 100 parts of the same coal, but finely ground in a ball mill, had no value as a binder and could not even be briquetted alone. This illustrates the effect of increasing the surface to be coated. Furthermore, in the early work with the plunger press, batches of mix were put into the fluxer over the press and kept there whilst adjusting the moisture and temperature conditions to the desired value. It was found, however, that if the batch was left several minutes in the fluxer it rapidly deteriorated, and after about ten minutes it acquired a sandy consistency and could not be briquetted without the addition of more binder. This deterioration was traced down to the crushing of the particles in this fluxer. The problem of crushing in the mixers and press in any commercial plant is worthy of study.

BINDERS

The binder used in any briquetting plant will depend on the nature of the material to be briquetted, and on the purpose for which the briquettes are intended, but the choice is restricted to those available in the locality. As binders are comparatively costly, the success or failure of a briquetting plant may depend upon the availability of a satisfactory binder at a reasonable cost, and upon the ability to reduce to the minimum the amount of binder employed.

The investigation of the properties, (melting point, penetration, viscosity, etc.) of typical binders has indicated that it is not yet possible to make specifications such that the more closely the binder conforms to the specifications the better its binding qualities are; nor is it possible to state that two binders of the same material with the same solubility, melting point, penetration, etc., are necessarily equally good. There are many factors which affect binding qualities and a binder good for one material and with certain equipment might be quite unsuited to other conditions.

The amount of binder required varies with its nature; with the strength and density of the material bound, strong particles taking little, weak and porous particles more; with the size of the material to be bound; with the pressure employed; with the thoroughness of the mixing; and with the uniformity of feeding and the skill of the operator.

A large number of organic and inorganic binders have been suggested and used as binders, but comparatively few have been a success commercially. Organic binders increase the volatile matter and therefore the smokiness in burning, although in some plants this defect is remedied by a subsequent heat treatment of the briquette. Inorganic binders increase the ash content in the briquette.

Single binders may be employed, such as coal tar pitch, natural asphalt, petroleum asphalt, lignite-tar pitch and wood-tar pitch, (each of these of either high, medium or low melting point), also sulphite pitch, flour, starch, clay, cement, water glass, magnesium oxy-chloride, etc. Treated binders may be used, such as chlorinated or sulphonated tars, blown or oxidized asphalts, pulped straw, sawdust, seaweed, etc. Almost any combinations of the above are possible, with or without the addition of tar or soft asphalt, with or without the addition of water, and with or without emulsification—a long list of possible binders, none perfect.

The two binders chiefly used are asphalt and coal-tar pitch. Coal-tar pitch is sometimes objected to on account of its smell, the briquettes, however, stand up well in the fire. Asphalt gives a less objectionable smoke, but the briquettes become weak, when heated in the furnace. Sulphur is sometimes added to any asphalt binder to improve the firing (coking) properties; but sulphur in a fuel must be regarded as deleterious, as it gives off an unpleasant odor when it burns, and causes corrosion. Sulphite pitch is distinctly less smoky, than either of the above, but used alone it does not make a waterproof briquette; this defect can be remedied by a low temperature baking or by replacing some of the sulphite pitch with asphalt or coal-tar pitch.

Von Delkeskamp and his coworkers are reported to have developed a process of colloidal briquetting in Germany. As far as the authors are aware, this process has not been successful. Preliminary experiments along these lines with Alberta coals were uniformly discouraging.

Investigations have also been made on the production of binders from straw, sawdust and other waste materials. The cellulosic substances were converted to a jelly-like mass before use. This can be done in several ways, but readily by cooking with a dilute solution of caustic soda in an autoclave and then pulping in a ball-mill. The fibers of the straw and wood, as such, appear to be valueless, as the more completely they are pulped the better the result. The

fiber might be valuable as a filler with porous materials. The temperature of cooking can be varied over a considerable range, but a 1 to 3 per cent solution of caustic soda at 180°C. gives rapid treatment without charring of the material. Briquettes made with these cellulosic binders are not waterproof, and unless some waterproofing agent, such as pitch or asphalt, is added, they will not stand weathering. Some English experimenters claim to have perfected a pulp binder which satisfies the binder requirements. They use a fermentation process for softening the material. This process has been developed commercially, as has also a seaweed binder.

A large number of starchy materials are suitable as binders. They are converted into paste with hot water either before or after mixing with the coal. Briquettes made with these binders can be pressed without difficulty, are hard, less smoky than briquettes made with bituminous binders and hold together well in the fire, but they are not waterproof and will not stand exposure to the weather, or even storage in a damp place. Bituminous material is often added to waterproof briquettes made with these binders. Very promising results have been obtained by use of flour and McMurray bitumen. The latter can be added either in the crude condition or as an emulsion.

FACTORS IN OPERATION

I. Blending of Coal. Blending is sometimes employed to improve the firing qualities of the briquettes. Briquettes made from non-coking coals do not stand up well when thrown onto a hot fire, but can be made to do so by blending with a good coking coal. A non-coking coal, that does not swell when heated, mixed with ten per cent of a good coking, bituminous coal and briquetted in the usual manner has been found to give briquettes which have excellent firing properties. Some non-coking coals which swell, however, require the addition of a higher percentage of bituminous coal to give satisfactory briquettes. The necessity for blending can sometimes be obviated by the use of a coking binder.

II. Sizing of the Coal. In many plants the coal must be treated as it is received, and the operator cannot control the sizing; although, if the percentage of dust were excessive it might be profitable to screen out a portion for use as powdered fuel. Where the coal is crushed for briquetting, the operator, to a certain extent, can control the sizing produced to suit the friability of the coal and his working conditions. A study was made of the problem of sizing in relation to briquetting, and the methods and results are given below.

For experimental work it was essential to remove the element of sizing differences, if other points were to be tested in comparable experiments. For such work therefore a considerable quantity of coal was screened through a series of screens, and for any experiment the desired amount of each size weighed out. The crushing which

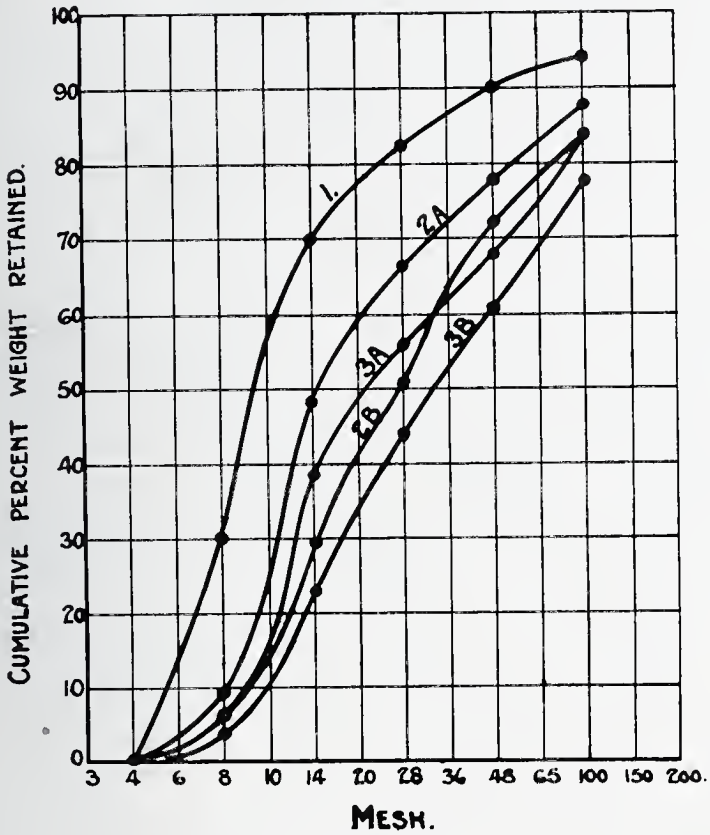

FIG. 4. CRUSHING DIAGRAM

	Coal A (strong)	*Coal B (friable)*
Original sizing	1	1
After mixing	2A	2B
After pressing	3A	3B

goes on is studied by taking a sample of the batch as it leaves the mixer and a sample of the briquettes as they leave the press, extracting the binder from these samples with benzene and rescreening the separated coals.

The crushing, other conditions being the same, varies markedly with the friability of the coal tested. An example of the difference noted

is shown in Figure 4. This gives the screen analysis of two coals as taken, one strong and one friable, and also the screen analysis of each coal after it had been crushed, first during mixing, and second during mixing and pressing. The ordinate of each point on the curve represents the cumulative percentage of weight retained on a particular screen. The abscissae show the number of mesh to the linear inch of the screens, plotted on a logarithmic scale.

It will be clear from the facts already cited that, within limits, the optimum sizing of coal for any plant is probably the sizing which undergoes the least crushing during mixing and pressing. The best batch of briquettes was selected from a large number of batches made with a particular coal and binder. The binder was removed by solvents and a screen analysis made on the separated coal. A charge of fresh coal was prepared with the same screen analysis, and briquetted as before; it was found first, that this made very good briquettes (better even than the batch first selected), and second, that the amount of crushing was small. A series of typical screen analyses was then decided upon, and a batch of coal made up for each screen analysis, and briquetted. This work was repeated to include two coals, semi-bituminous and sub-bituminous; and two binders, asphalt and coal tar pitch. The results obtained were similar, regardless of the coal or the binder. Figure 5 shows the results with three screen analyses using a sub-bituminous coal with an asphalt binder. Diagram (1) shows the three screen analyses superimposed on the same chart, (2) (3) and (4) show for each screen analysis the crushing undergone during mixing and pressing. The area between the lines A and C in each case is a measure of the crushing. The conclusion arrived at was that the best screen analysis was one which approaches a straight line when the screen sizes are plotted on a logarithmic basis as shown, always provided there was not too much coarse or too much fine coal present. Coarse coal gives a rough briquette from which there is a high loss by abrasion, and fine coal requires considerably more binder, due to increased surfaces to be covered. It was found that screen analysis No. 26—the nearest to a straight line in Figure 5—usually gave strong briquettes (low loss in rattler test) with medium density (apparent specific gravity); screen analysis No. 17 gave medium strength briquettes with a high density and screen analysis No. 31 gave somewhat weaker briquettes with low density. Thus screen analysis 26 was slightly better than 17 and distinctly better than 31. This is not in complete agreement with

the crushing results, as 31 underwent less crushing than 17. No. 31, however, contained too much fine coal.

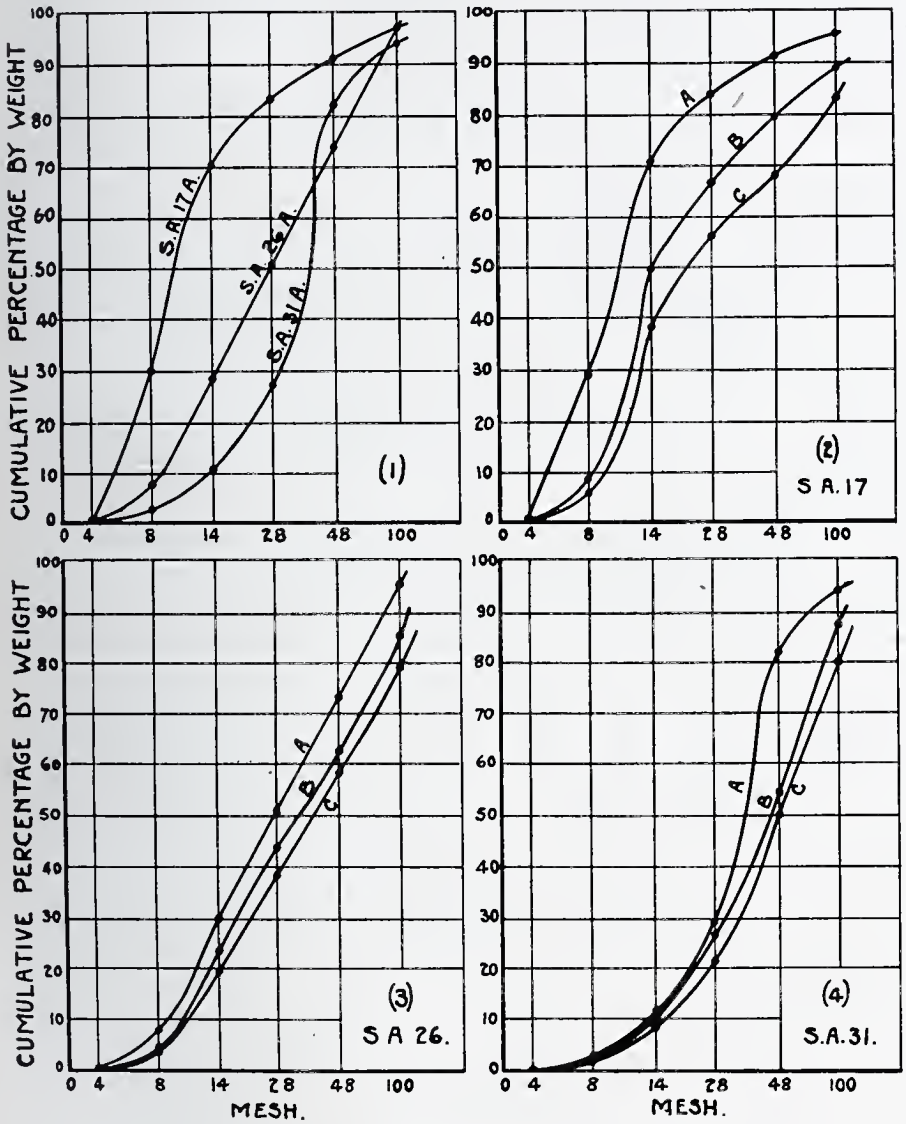

FIG. 5. SCREEN ANALYSES OF COAL

It is not suggested that the same screen analysis would be the optimum for all coals and all equipment, but only that this method of attack is generally applicable and gives valuable information.

III. Introduction of Binder. The binder may be added in solid,

molten or atomized form. A hard pitch can be roughly crushed and then dry mixed with the coal by passing them together through a crushing plant. This method reduces the amount of mixing required but may give trouble if the coal is warm. A soft pitch, or asphalt, is commonly heated until fluid and run on to the coal in the mixer through a regulating valve. The modern process of spraying the binder on to the coal in atomized condition is said to reduce the quantity of binder required.

The use of emulsions as binders has attractive possibilities, as the bulk of the binder is increased and its viscosity decreased by emulsification with water. However, as is indicated by the Trent process, coal has a tendency to break down such emulsions with the expulsion of water. If the emulsion were destroyed before it had covered the coal surfaces, little or no advantage would be gained by this method of introducing the binder. Work on this subject is in progress.

IV. Moisture and Steam. In ordinary commercial practice with a pitch or asphalt binder the raw coal, if moist, is first dried then crushed, if necessary, and the binder added; the coal and binder are first mixed dry after which steam is blown in to flux the binder. Only rarely is a dry mixture briquetted. The preliminary drying of the coal avoids trouble in the crusher, but where crushing is unnecessary this drying could in some cases be omitted. In our experiments many apparently contradictory results have been obtained which makes it clear that more work is necessary along these lines. With some coals and binders the best briquettes are made when water is altogether excluded, whilst with other coals and binders the reverse is the case. Excellent briquettes have been made by adding the binder directly to wet coal, as for example in the Trent cleaning experiments already described. The wetability of the coal with water is probably an important consideration, and the readiness with which the binder displaces water as the wetting film on the surface of the coal must also be considered. In a number of experiments it was found that coals which are easily wet could be briquetted wet with advantage, whilst with coals which are difficult to wet the reverse was the case.

It must not be overlooked, however, that water and steam are frequently of value in briquetting operations. Thus the batch may be rapidly heated to the desired temperature for mixing by means of the introduction of live steam. Again, mixing is done most quickly

and with the least consumption of power if the batch is hot and the viscosity of the binder low, but if it is too hot when it goes to the press the briquettes will lack strength in the press and as they leave it. The required cooling can be quickly effected by adding water. A hot, dry mixture, moreover, is apt to stick to the plungers or rolls, where a moist mixture would give no trouble. The difficulty with regard to sticking can be reduced, and a hotter batch pressed if the rolls or plungers are wet and cooled by spraying or otherwise.

In general it is suggested that the established practice although the best for some coals and binders may be far from best with other coals and binders, and that this problem of the use of water and steam in briquetting requires more study and consideration.

V. Temperature and Time of Mixing. The temperature of mixing should be high enough to render the binder quite fluid and thus insure every particle of the coal being covered with binder. It has been found experimentally that the temperature required with similar binders will be closely related to their softening point, but it cannot be said that the minimum temperature for such binders will be in each case a certain number of degrees above its softening point, because with rise of temperature the viscosity of some binders decreases much more rapidly than does that of others. The temperature of mixing must be varied with each binder to give the desired low viscosity. The maximum viscosity that can be used satisfactorily will be determined by the time allowable and power available for mixing. A longer period of mixing with a viscous binder may give as thorough mixing as a shorter period with a less viscous binder. In a commercial plant, the cost of increased temperature may be balanced against the saving resulting from decreased time and power.

Experiments indicate that there is little advantage to be gained by prolonged mixing when the temperature of mixing is sufficiently high for quick mixing. A slightly denser briquette can thus be made, but too prolonged a treatment results in an inferior product.

VI. Temperature, Pressure and Time in Press. The density, and consequently the strength of a briquette, can be increased by decreasing the viscosity of the binder in the mix as it goes to the press, by increasing the pressure employed, and by increasing the time the pressure is maintained. A small change in one or all of these factors at first may show a marked improvement in the product, but as denser and denser briquettes are produced a point is soon reached where a very marked increase in pressure, for example, has practi-

cally no effect on the density. The density of the briquette can most readily be increased by raising the temperature of the mix so that the particles flow readily to the positions which leave the smallest voids, but the maximum practical temperature is soon reached above which the briquettes lack coherence and expand and break as they leave the press, or break in falling on to the cooling belt. An increase of time of pressing necessitates a reduction in output of the press. An increase of pressure is probably the most satisfactory method for increasing density, but the limit, even here, is soon reached at which the increased strength is not commensurate with the increased cost. If further strength is still desired it will probably be necessary to increase the binder.

Experiments to test the effect of increased temperature and increased magnitude of pressing are more easily carried out on the plunger press and this press was principally used. Comparative tests on the roll press indicated that the mixture had to be cooled to a lower temperature in order to make good briquettes.

TRANSFORMATION OF FINE BITUMINOUS COAL INTO SUBSTITUTES FOR ANTHRACITE

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Part I

In a general way, the manufacture of an artificial anthracite by carbonization of fine particles of bituminous coal at low temperature constitutes a doubly profitable operation. On one hand, it permits a recovery of liquid and gaseous by-produets, which is as interesting as that in the ordinary processes of distillation at low temperature; and on the other hand, it transforms fine particles of little value into a product perfeetly calibrated and of high commercial value. The essential point which characterizes a process such as the one which is the subject of the present discussion, and of which the technical perfection is due to the Societe de Recherches et de Perfectionnements Industriels de Paris (Society for Industrial Research and Improvement of Paris), is that the solid by-product of the distillation is no longer a semi-coke, strictly speaking, but a very compact agglomerate presenting most of the physical and chemical properties of natural anthracite, and capable of being utilized as such in domestic furnaces with continuous fire and in industrial gas-generators.

We are beginning to realize almost everywhere that the liquid by-products, whatever be their value, (which is, after all, often overestimated), cannot suffice to make distillation at low temperature profitable, if semi-coke, which is the most abundant by-product, finds a poor market. In a factory for the manufacture of artificial anthracite, it is the solid by-product which constitutes the principal source of profit, without the yield of liquid combustibles being neglected on that account.

From the economic standpoint, a cheap combustible equal to natural anthracite is capable of finding a very great market in countries like France, Canada, Italy, Switzerland, etc., whose budgets are burdened by the annual importation of substantial tonnages

of anthracite. Even in England, we are convinced, the manufacture of a combustible analogous to that manufactured in France under the name of "Trenthracite" would meet the needs of the English consumer of "smokeless fuel." As for the United States, in spite of its enormous wealth in natural anthracite, it is certain that a great future is open to artificial anthracites manufactured from inferior combustibles. The case in which the raw material is very rich in cinders has, moreover, been the subject of thorough study by the Trent Process Corporation.

Technical Difficulties

It is a question of reconstituting, not only in the laboratory, but also in industry, a product which nature has fabricated, in the course of long geological periods, in the bosom of the earth. Of the three factors employed by nature: time, pressure, and temperature, we can only utilize the third, within limits of the same magnitude as in the natural phenomena. In the phenomena of metamorphism which have resulted in the formation of the anthracite, it is not the temperature which has been the principal factor, but the pressure acting over a very long period of time.

Nevertheless, in certain cases, it is possible to improve upon nature by giving to the artificial anthracites supplementary qualities not possessed by the natural anthracites: greater combustibility and reactivity, readier inflammability, less fragility, fixed composition and proportion, and total absence of stones and powder. All these qualities are important, especially for a choice domestic combustible. They have a commercial value which greatly facilitates putting a new combustible on the market.

Characteristics of the Product to Be Obtained

These characteristics depend, on one hand, on the kinds of coal one uses, and on the other hand, on the customs of the consumers.

For France, whose conditions are best known to us, the most desirable characteristics are the following:

Ash. The ash content must be less than 7 per cent. That is the amount of the ash content of good natural anthracites of English, German, or Belgian. It is absolutely indispensable that the ash should show no tendency to form clinkers. By taking the temperature of 1,300°C. as lowest fusibility point of the ash, one is certain

that no clinkers will be produced in the domestic slow-combustion fires where the temperature is not as high as in the industrial furnaces. Moreover, it must be noted that an artificial anthracite, manufactured as we are going to explain, gives a finer and more pulverulent ash than the pieces of natural anthracite, and this peculiarity helps to avoid the formation of clinkers, and to facilitate the evacuation of the non-combustible residue.

Volatiles. The volatile content must not exceed 7 per cent. It must not be less than 5 per cent, because it is advisable to leave in the product some volatile substances to facilitate inflammability and recoveries. It is useless to give to artificial anthracites defects which certain natural anthracites possess (difficult inflammability, lack of flexibility during combustion, and poor reactivity).

Physical Properties. These are no less important than the chemical properties. The resistance to crushing must be greater than 100 kgm. per square centimeter, and the cohesion (a quality which is not a component of the resistance to crushing), must be as great as that of a good coke. In addition, the product must be able to undergo storage in the open air in contact with humidity and heat, without any damage. This requirement excludes the use of agglomerating agents, which, like sulphite of cellulose, facilitate the disintegration of products exposed to the air. The density must be regulated according to the use one wishes to make of the combustible. It must be noted here, that the cokes of gas factories or the metallurgical cokes, which are being used more and more as furnace fuels in Germany and in certain provinces of France, have a density of half that of anthracite, without their development being stopped on that account. If bunkers and boilers have been provided large enough, and if the draft can be conveniently regulated, nothing hinders the use of combustibles of low density. The best density for artificial anthracites must be 15 per cent lower than that of natural anthracite.

Size. The constancy of size gives a considerable advantage over natural products. Without doubt the natural anthracites are carefully sorted; but it is manifestly impossible to deliver to the clientele pieces identical in weight and in form. Yet, the problem is solved by the manufacture of artificial anthracite by grinding prior to the distillation. In a heating apparatus, a mass of combustibles consisting of all identical pieces burns with perfect regularity. No air-shaft is formed, the draft is quite steady, and the product of the combustion is better. Such a boiler is therefore easier to operate

under these conditions than with a natural coal composed of pieces of variable dimensions.

Process of Manufacture

The manufacture comprises two phases: first, the preparation of the paste and its agglomerating constituent; second, the distillation.

The initial step in the first phase is the extraction of the cinders. This can be done at the mine, by washing with water according to the known processes; it can also be accomplished by washing with oil, notably by the Trent methods. These latter have been applied in France by the Societe des Combustibles Purifies (Purified Combustibles Company) in its factory at Lapugnoy (Pas de Calais). They offer the advantage of having an extremely high yield in coal and oil, and for this reason they are unusually interesting. The ingenuity of the inventor and the care with which the Trent Process Corporation is constantly improving its methods, lead one to believe that there is a great future for this process in Europe, the only region of which we can speak with knowledge.

Since it is necessary, at the end of each Trent purification treatment, to recover the oil in order to use it in the following operation, the Purified Combustibles Company, licensee for France of the Trent processes, is also licensee for France of the distillation processes of the Society for Industrial Research and Improvement (France).

The manufacture of artificial anthracite can therefore be effected by starting with fine particles washed either in water or in Trent butter. In both cases, the first phase of the manufacture comprises the elaboration of a suitable paste, and its agglomeration. In certain cases, it may be advantageous to mix the coals washed in water with a Trent butter; one then comes to a mixed formula between the agglomerate of pure Trent butter and the agglomerate without Trent butter.

It is the distillation of these agglomerates—those with Trent butter, those without Trent butter, or those mixed—which constitutes the second phase. The distillation process of the Society for Industrial Research and Improvement is being used at present on an industrial scale at the factory at Lapugnoy. This factory has a production capacity of 50 tons of artificial anthracite a day, and it is going to be greatly enlarged.

The principal characteristics of the manufacture have to do with: (1) the agglomeration, and (2) the distillation.

Agglomeration. The agglomeration previous to the distillation is a principal characteristic of the process. If one starts with a coal purified by the Trent method, the oil used for the purification serves as adhesive agent for the agglomeration. Likewise, the oil contained in the Trent butter allows one to incorporate in the mass, without the addition of a supplementary agglomerating agent, a quantity of variable coal, with the degree of fineness of this coal, and capable of being twice or three times as heavy as the quantity of purified coal and of oil. If one starts with a coal washed in water, the agglomeration takes place after the addition of an adhesive agent, as in the ordinary processes of agglomeration.

Whatever be the material used, it is essential to proceed, before the baking, to a perfect agglomeration. This is one of the conditions of success.

The agglomeration industry has remained, until the present time, in the experimental stage, and the rôle of many factors remains unexplained. The principal elements which come into play are:

Size of the grain
Amount of humidity
Nature of the agglomerating agent and its proportion
Degree of malaxation of the paste
Temperature of the paste
Rate of compression, etc.

All these elements are easy to study in the laboratory.

For our laboratory experiments, we use an inclined mixer with a capacity of 2 to 3 kgm. of material, equipped with a paddle-shaft of adjustable speed. The press is a hydraulic one, permitting the increase of compression to 900 kgm. per square centimeter. The pressing mold is equipped with a reservoir, allowing it to be heated by a liquid metallic bath, all of which makes it possible to perform agglomeration experiments up to a temperature of 400° to 450°C. The crushing strength of agglomerates is measured by a lever apparatus which allows precise measurements from a few grams to more than 200 kgm. In general, an agglomerate acquires its maximum resistance only at the end of several hours, and for certain agglomerating agents which undergo a hardening by exposure to the air, the maximum resistance is reached only at the end of several days. It is necessary to take this fact into account in measuring resistances.

In the agglomeration considered as preparatory operation to the baking, the two principal elements are the following: (1) rate of compression, and (2) nature of the agglomerating agent.

1. Rate of compression. The laboratory experiments carried out with a hydraulic press of adjustable pressure have shown the importance of the rate of compression. But in practice it is difficult to vary the compression much, because one uses "boulet" presses with moulding wheels.

2. Nature of the agglomerating agent. It is much easier to control the second element. Each coal must be the subject of special study, in order to determine which agglomerating agent will give the product, after its baking, the physical aspect and qualities sought. Up to the present time, the studies which have been made of carbonization at high and at low temperature have furnished considerable information concerning the coking of pit-coal alone, but the data on the coking of agglomerates containing an adhesive agent are much more rare. Now, the addition of an agglomerating agent may improve in a very remarkable way the coking of a coal, either chemically, by the contribution of new elements, or physically, by the modification of the compactness of the mixture, its structure, its penetrability by heat, etc.

This physico-chemical action of the agglomerating agent upon the coking of pit-coal is all the more pronounced as the adhesive agent is greater, and as its mixture with the coal is more intimate; it is thus pushed to a maximum for agglomerates with a Trent butter.

In fact, it is upon agglomerates of Trent butter that this action of the adhesive agent on the coal during the distillation has been the most marked. It has been known for several years that it is possible to obtain a coke of average quality by distilling at low temperature an amalgam composed of a coal and an oil, the residues of which, after separate distillation, show no trace of coking. In 1922 Walter Trent ingeniously pointed out the possibility of obtaining a real substitute for anthracite by distillation at low temperature of a Trent butter previously briquetted, the distillation being done by a current of steam superheated to about 500° to 600°C.[1]

In a series of experiments in 1925, in the laboratory of the Society for Industrial Research and Perfection (of Paris), we undertook to study the action of an agglomerating agent on a coal in a particularly

[1] French patent number 561,557 of January 29, 1923, same as American patent of February 13, 1922.

difficult case. The question was to ascertain if, by choosing a suitable oil, one could avoid the expansion and setting in mass of certain coals having high content of volatile matters and weak coking power. We experimented on agglomerates from 10 to 25 per cent adhesive agent, incorporated under water by the Trent process. The principal agglomerating agents studied were: coal tar, anthracene oil, and mixtures of these two. The most important conclusion of our study is that we avoided the expansion and setting in mass of the solid residue by using as an agglomerating agent anthracene oil, which has a negligible pitch content though retaining sufficient agglomerating properties. The solid residue of the distillation of these agglomerates is analogous to an anthracite, and can be used as such. This method of treatment makes it possible to obtain a very hard and compact semi-coke, a quantity of oil perceptibly equal to that of the agglomerating agent used, and a quantity of gas varying from 2 to 15 per cent, according as the distillation is more or less extended.[2]

It often happens that the qualities of the agglomerating agent thus chosen to obtain a good baking are not the best qualities for the Trent purification or for the agglomeration in the case of direct treatment. One is then led to a supplementary study in order to reconcile these varied needs. It is with this in mind that we studied the action of sulphur on certain oils, and more especially on anthracene oils, in order to increase their qualities of agglomeration. It is known that sulphur is soluble in tars and oils of coal and petroleum, and that it increases their viscosity; but every agglomerating agent which contains a large quantity of sulphur must be rejected, especially if the coals treated are already sulphurous, because sulphur deteriorates heating apparatuses. We found, that by treating hydrocarbons with sulphur at a high temperature (about 250° to 350°C.), for a sufficiently long period of time, it was possible to dehydrogenize them partially, without contaminating them with an undesirable quantity of sulphur.[3]

The viscosity and the drying properties are greatly increased by this treatment. We demonstrated, moreover, that these hydrocarbons were made adhesive by the same treatment, and could be used as agglomerating agents.[4]

[2] Report made to the Academy of Sciences of Paris, August 22, 1927.

[3] Report made to the Academy of Sciences, June 4, 1928.

[4] Report made to the Academy of Sciences, July 23, 1928.

Agglomeration. The distillation apparatus, of which we are giving the description here, is especially designed for the treatment of agglomerates; nevertheless, it can be used for the treatment of raw materials, provided they do not present themselves in the form of fine particles or of powder.

A furnace for the purpose of distilling the agglomerates must not cause the matter to undergo handling and shocks during its distillation. This necessity is all the more urgent because the majority of agglomerates pass through a zone of greater friability at about 200° to 300°C. An agglomerate with a resistance of 60 to 80 kgm. prior to distillation can lose as much as 80 per cent of its resistance at 200° to 300°C., and might crumble should it be submitted to shocks about this temperature. This zone of friability corresponds, in general, to the evacuation of humidity (hygroscopic water plus water of constitution). Revolving ovens and mixing ovens, vertical or horizontal, are therefore to be eliminated from consideration.

It is known that the speed of heating is an important factor. Certain agglomerates can be distilled very rapidly without any disadvantage, others must be subjected to progressive heating. It is particularly indispensable to bring certain agglomerates to temperatures around 350°C., in order to overcome their tendency to swell. This is a finding in accordance with the experiments of Illingsworth. Thanks to preheating, one eliminates the constituents before the period of the softening of the coal, which avoids inflation and produces in certain cases an appreciable contraction, all of which increases the density of the product and improves its appearance.

External heating, which permits no control of the speed of heating, and which distills very irregularly the layers of coal in contact with the heated surface, must therefore be rejected.

To allow the control of the speed of heating, we first constructed a laboratory oven with several chambers, the temperatures of which varied between the atmospheric temperature and 600°C. The agglomerates to be distilled are placed in small metallic receptacles with perforated sides. Each receptacle remains in each chamber and the time necessary for subjecting the agglomerates to the standard of heating deemed the best. This arrangement was considered preferable to that by which each receptable would be left immovable in a chamber during the entire time of the operation, and the temperature of the chamber varied according to the standard desired, because in the latter case, the walls of the oven are subjected to periodic

variations of temperature, which cause the walls to deteriorate and diminish the thermic efficiency of the operation.

The heating fluid adopted is steam superheated to 600°C.

Calculation and experience show that the distillation of a ton of agglomerates requires about 1.5 tons of steam superheated to 550° to 600°C. One can see that, excepting special cases where one could use steam at low cost, the vaporization of such a large quantity of steam is expensive, and it is much more economical to have the steam circulate in a closed circuit, condensing as little as possible of it. It is true that the recovery of the oils and gases is more nearly complete in a closed circuit than in open circuit, where all that comes out from the oven is condensed as a unit. Nevertheless, the recovery of by-products in a closed circuit has the advantage of furnishing products little hydrated, whereas in an open circuit, the separation of the primary oil and of the water of condensation is a particularly difficult problem, because this oil has a density approximately that of the unit, and because it is readily emulsifiable. Special precautions are taken, in the case of the closed circuit, to avoid the return of the distillation products to the superheater.

Figure 1 is a diagram of our laboratory oven. This oven is capable of distilling 10 kgm. of agglomerates per hour. It is therefore a semi-industrial apparatus. The steam is superheated to 600°C. in a superheater consisting of about 10 coils of an annealed steel tube having an inside diameter of 30 mm., contained in a refractory casing, and heated at the bottom by eight gas-burners. In the case of continuous distillation, one can burn in the superheater the rich distillation gas gathered in a gas tank. The exterior surface of the coil, for calorization, is coated with a thin coat of alumina which assures its preservation indefinitely. The superheated steam circulates then in pots C, M, and F, the temperatures of which range from 600° to 200°C. These three pots are carefully insulated. It is possible to increase the average temperature of the last two pots, by admitting directly into them superheated steam at high temperature, by means of the piping and the supplementary valves represented in the diagram.

One can see that in order to regulate the speed of distillation one has to deal with the three following factors:

(1) Temperature of the steam upon leaving the superheater, which depends on the number of lighted burners and the rate of the flow of steam.

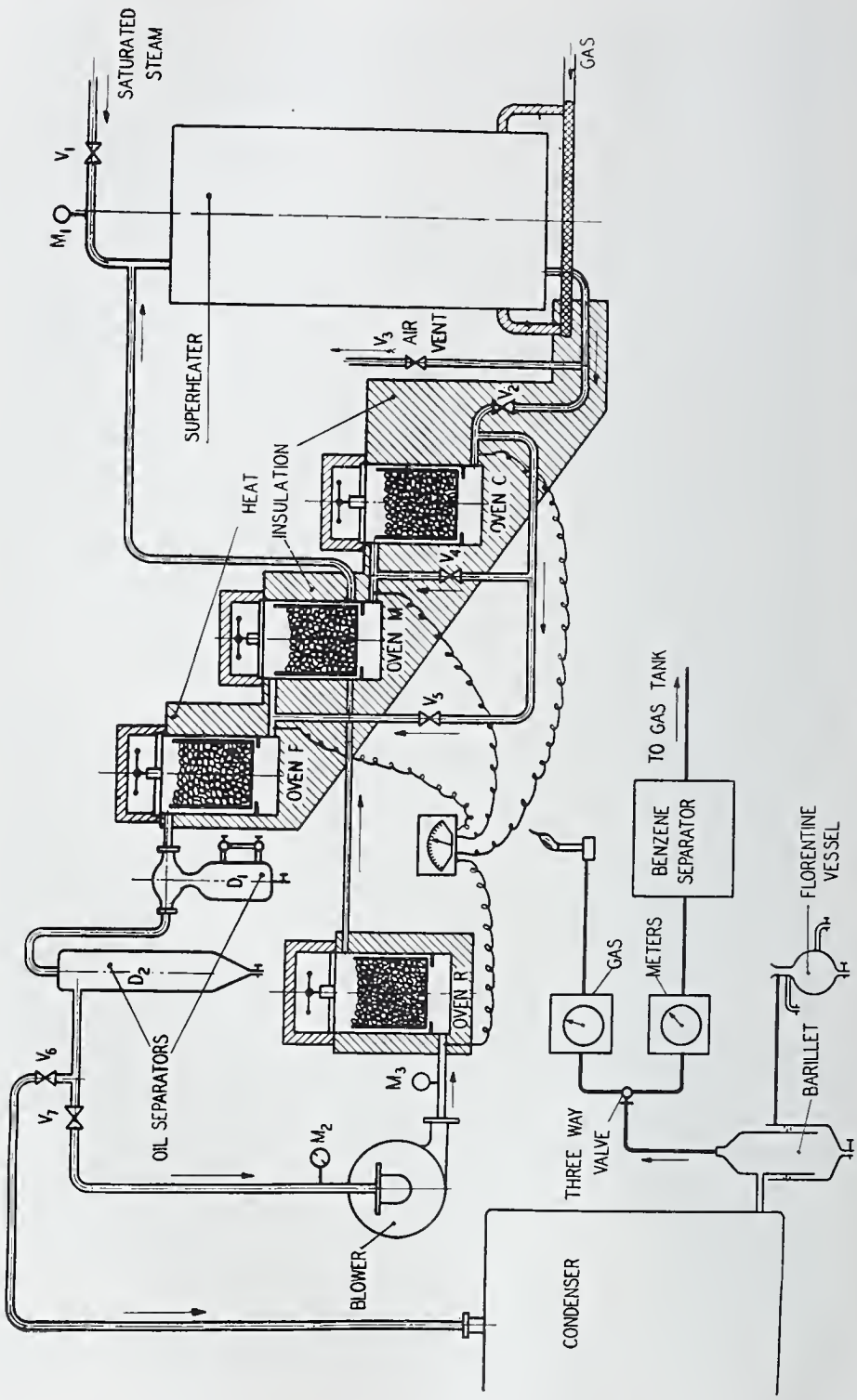

FIG. 1. APPARATUS FOR THE BAKING OF AGGLOMERATES BY SUPERHEATED STEAM

(2) Variation in temperature between the three baking pots, which depends on the degree of opening of the supplementary valves for the direct admission of steam into pots M and F.

(3) Length of stay of each basket in each baking pot.

It is evidently possible, by combining these three regulations, to vary the speed of heating within considerable limits, and to effect either a progressive or an irregular distillation for a given zone of temperature.

Upon leaving the last pot, the steam passes into a cooler (not on the diagram), which lowers the temperature of the tar-saturated steam to a temperature near its dew-point, in order to allow the condensation of the liquid by-products; one should avoid all useless condensation of water. The heavy and medium oils are gathered in two oil-removers D_1 and D_2. Moreover, for the distillation of agglomerates having a very great tar yield, supplementary oil-removing apparatuses are interpolated between the baking pots (these apparatuses do not appear on the diagram). The steam is then received by a ventilator which sends it into a fourth pot, where it is reheated by contact with the agglomerates, the distillation of which has been completed, and from which one thus recovers considerable heat. Then, it returns to the superheater for another circuit. At the coldest point of the circuit, one makes a continuous removal of steam, which is then sent into a condenser in order to retrieve the light substances and the incondensable gases. Upon leaving the condenser, the light and medium oils, together with some water not yet recovered are deposited in a small barrel; the last traces of oil are gathered in a Florentine vessel. The gases, after passing through a gas-meter and into a small contrivance for the removal of benzene, are sent to the gas-tank.

PART II. DESCRIPTION OF THE LAPUGNOY PLANT

The plant which is now in full operation consists of three distinct parts:

The Trent cleaning plant,
The mixing and briquetting plant,
The distillation plant.

The crude coals on their arrival, are poured into bunkers the construction of which permits the mixing of coals from different sources.

They can then be sent directly, at will, either towards the Trent cleaner or towards the mixer and briquette press.

In the first case when the coals are received in the form of crude and ashy slack, they pass successively through the following apparatus: Carr crusher, storage hoppers, Allis Chalmers tube crusher (grinder), Dorr screener, amalgamator, coconut fiber mat dryer, and vertical dryer. The Trent butter coming from the dryer is sent to the press.

In the second case, the coals which arrive in fine particles washed with water take the following course: Carr crusher, vertical dryer, shaker (movable) hopper; from there they go to the press.

The agglomeration or briquetting apparatus comprises: paddle screw, mixer, rotary press. The production capacity of the plant in crude artificial fuel is two hundred and forty tons a day.

Distillation Furnace

The distillation furnace is the reproduction, on an industrial scale, of the laboratory furnace described before.

It is composed of four cylindrical chambers of sheet steel, with an inner diameter of 2.20 meters, and about 1.80 meters for their height. The foundations are elevated two meters above the level of the floor. These chambers are connected with an independent superheater, by pipes permitting the circulation of steam by means of turbo-superchargers, in the following manner: superheater, chamber No. 3, chamber No. 2, chamber No. 1, cooler, tar recuperation apparatus, chamber No. 4, turbo-supercharger, back to superheater.

The metal work composed of the walls and pipes is covered with heat insulation material in boxing supported by metallic frame work.

The crude artificial fuel briquettes are loaded, either directly after arriving, on a metallic mesh conveyor that takes off the rough edges, or after a period of storage in cylindrical receptacles of perforated steel, that are 1.80 meters in diameter and 1.28 meters in height. The volume of one of these receptacles corresponds to that of a furnace chamber.

The chambers are opened at the bottom when drawing off the charge to prevent loss of heat by convection. This arrangement is an essential element of their construction. The bottoms of the chambers are formed of platforms that may be moved up and down, which are mounted on pistons of hydraulic jacks that can be lowered sufficiently to permit taking the buckets out of the chambers.

The horizontal platform which forms the bottom of the distillation chamber is provided with two circular projections which enter corresponding asbestos lined notches made in the base of the chamber. The movable floor of each chamber when rising to fit against the bottom of this chamber, makes tight connections which prevent all loss of the fluid when it passes through the material to be distilled. The steam, coming through a circular ring that surrounds the base of each chamber, enters the chamber through openings made in the platform.

To obtain good distillation the heating fluid much circulate freely throughout the material treated. For this purpose the circulation canals formed by the open spaces left in the agglomerate filling a bucket must not be obstructed by any material which would prevent the circulation of the fluid and thus hasten the solidification of the agglomorate during its distillation.

The crude briquettes should be loaded in the buckets only when their resistance is sufficient to prevent the formation of dust during the filling of the buckets. On the other hand, the rate of flow of the fluid must be fast enough to assure the evacuation in vesicular form of the substances produced by the condensation of the oil vapors in contact with the walls which become colder and colder as the fluid progresses in its circuit. Moreover each bucket is held on each platform by a ring riveted to the base of the bucket and extending several centimeters beneath its bottom. This ring fits into an asbestos lined basin attached to the platform. Due to this supplementary connection the steam coming from the pipes is directed towards the center of the mass through the perforated bottom of the bucket.

The platforms are carefully heat-insulated at their bottom as well as at their top. This is an indispensable precaution to overcome the effects of expansion which interferes with the tightness of the joints. To obtain perfect tightness it was necessary to equip the movable platform at four points diametrically opposite (in pairs) with guides that slide in vertical grooves when the platform moves without counteracting the thermal expansion.

Operation of the Furnace

Below the four chambers is placed a rolling framework C moving on two rails R (Fig. 2). Its length exceeds the total length of the four chambers by the length of one chamber. It is moved longitu-

dinally by two hydraulic pushers. The extent of its movement limited by the stops, is equal to the length of any one of the chambers. The buckets to be put into the furnace are conveyed on trucks. These buckets have handles that can be fitted on hooks *a* attached to the movable framework.

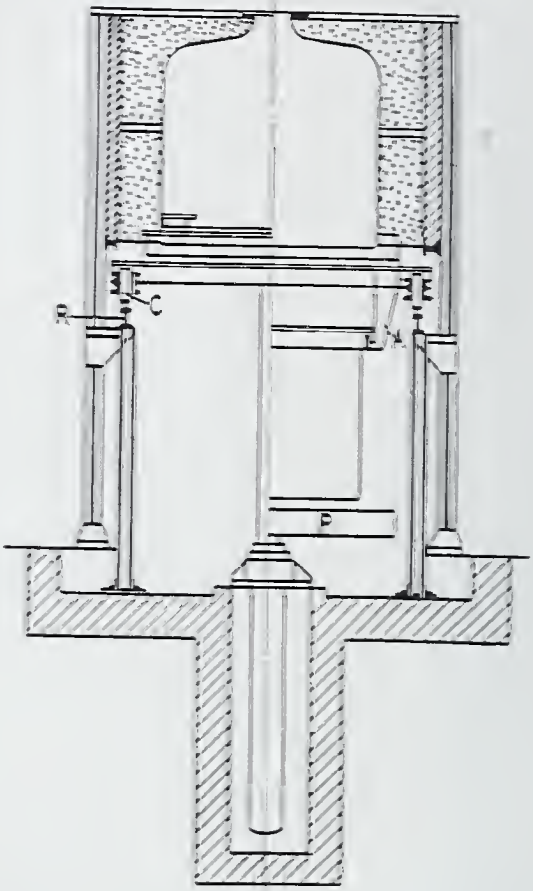

FIG. 2. CROSS SECTION OF A DISTILLATION CHAMBER

The furnace contains, in the order of the progression of the operation:

In chamber No. 1, a bucket for preheating,
In chamber No. 2, a bucket in which the distillation begins,
In chamber No. 3, a bucket in maximum distillation,
In chamber No. 4, a bucket that is cooling.

At the conclusion of the distillation, by a combination of the longi-

tudinal movement of the rolling framework and the vertical movement of the hydraulic jacks, the following operations are simultaneously taken care of: the bucket in No. 4 is taken out, the bucket in No. 3 passes into chamber No. 4, the bucket in No. 2 passes into chamber No. 3, the bucket in No. 1 passes into chamber No. 2, a new bucket is put into chamber No. 1.

Controlling and locking devices are provided in order that the operation of the rolling framework (chassis) and of the jacks take place in the order desired, and that the circulation of the steam may be shut off and shifted while the chambers are open. The total duration of the simultaneous charging and drawing off operation is less than two minutes; the losses by convection and combustion are quite negligible.

The distilled artificial fuel comes out of chamber No. 4 sufficiently cooled to be loaded directly on cars.

Superheater

The steam is superheated in a tubular independent superheater capable of superheating 6,000 kgm. of steam per hour to 650°. The hottest pipes are protected by calorizing.

Turbo-superchargers

The turbo-supercharger installation is composed of a back-pressure monocellular turbine coupled directly to a supercharger of the monocellular type with radial flanges of reduced dimensions and simple forms to make it as slightly sensitive as possible to the effects of expansion and to reduce the possibility of fouling. Moreover to avoid the heating of the oil, the supercharger has no bearings; the wheel of it is mounted in an opening out of perpendicular on the prolongation of the turbine shaft.

On account of the space occupied, the turbo-supercharger group has not been placed in the coldest point of the circuit, but at the exit of chamber No. 4. The temperature of the steam extracted by the supercharger is accordingly rather high (from 200° to 300°C.). Moreover the steam coming into the supercharger is still charged with tarry vesicles. We profit by the tar removing power of the centrifugal extractors by using the wheel of the supercharger as a supplementary tar remover. The installation which has been in use for a year and a half is performing good service and shows no signs of fatigue.

Speed of Heating

The operations of charging and drawing off are accomplished at a regular rate. Each bucket remains the same length of time in each of the chambers. During normal operation the temperature of each chamber is a periodic function of the time whose length is equal to the interval of time between two drawings. In general this time is one hour; each bucket remains thus:

One hour in chamber No. 1 where the temperature rises to *T1*,
One hour in chamber No. 2 where the temperature rises to *T2*,
One hour in chamber No. 3 where the temperature rises to *T3*,
One hour in chamber No. 4 where the temperature falls to *T4*.

The temperatures *T1*, *T2*, and *T3* are distributed between 0 and 600°C.; they are regulated by the operating engineer of the distillation, according to the nature of the coal treated and of the anthracite to be produced. For this purpose auxiliary pipes permit the introduction of high temperature steam to chambers No. 1 and No. 2; thus the operating temperatures *T1*, *T2*, *T3* can be modified to obtain the law of the heating desired.

The normal duration of distillation is three hours. By adding one hour for cooling the total time that a bucket remains in the furnace is four hours. The production capacity of the furnace is about fifty (metric) tons of artificial anthracite every twenty-four hours.

Closed Circuit Operation

Closed circuit operation, in opposition to its economic advantage, makes the removing of the oil a more delicate process. The problem is the following:

1. To prevent fouling by catching the maximum of condensable products at the exit of each distillation chamber,
2. To prevent the return to the superheater of the hydrocarbons not yet condensed, or their cracking in the superheater, at the exit of each chamber.

The oil removal apparatus has been planned (1) to condense the least possible water and to obtain non-hydrated oils, (2) to create minimum losses of charge.

From the superheater the steam is led to chamber no. 3, where it drains the heavy distillation fraction of the agglomerate. Between chambers No. 3 and No. 2, it is impossible to catch these heavy fractions which are in the state of vapor. Accordingly these vapors

are carried along into chamber No. 2. The flattening of the fluid stream through the supply pipes in the chamber and through the agglomerate in this chamber, as well as its cooling, causes a beginning of condensation of the heavy fractions coming from chamber 3; these fractions suspended in the steam, take on a vesicular form; at the exit of chamber 2, they are caught by tar removers. The same phenomenon reproduces itself in chambers No. 2 and No. 1. At the exit of chamber No. 1, a cooler lowers the temperature, and oil removers continue the cleaning out of the tar, which is completed by the centrifugal action of the supercharger and by another oil remover situated at the entrance of the superheater.

At the coldest point in the circuit there is a continuous withdrawal of steam which is condensed integrally to collect the light oils and fixed gases. The gas collected is generally enough to heat the superheater. (Gas burners have not yet been installed at Lapugnoy.)

The remainder of the saturated steam necessary to compensate the condenser for the continual loss is injected into the circuit of the exhaust steam of the turbine that drives the supercharger.

In the present manufacture the recuperated oils are used again in the agglomeration.

Conclusion

The distillation furnace at Lapugnoy put in operation about two years ago, has produced thousands of tons of artificial anthracite called "Trenthracite." It also possesses advantages common to all processes of interior heating, a certain number of additional advantages, notably that of the thermal yield, certainty of operation, and easy and accurate regulation of the velocity of heating.

The present plans of the Societe des Combustibles Purifies at Paris are to add three new units to the distillation plant which will permit the manufacture of two hundred tons of synthetic anthracite per day.

Product Manufactured

The artificial anthracite called "Trenthracite" manufactured at Lapugnoy comes in the form of briquettes whose form has been chosen purposely. Its characteristics are similar to those of natural anthracite which have been defined in the first part of this paper. This new fuel has been selling well in the French market, and this is justified by its technical qualities. In all types of slow combustion

furnaces (hearths) and in open furnaces this combustible shows remarkable results. The regularity of its composition and of its standard form its high radiating power, (particularly interesting in case of boilers with a large furnace), its flexibility in following variations in operation, as well as the possibility of burning it slowly, the very small proportion of unburned combustible in its ashes—all these qualities contribute to increasing the yield resulting from its combustion. The efficiency of domestic heating apparatus can be increased 10 to 15 per cent by its use, and the consumer who has neither the time nor the inclination for cleaning, appreciates the total absence of stones and coal cinders.

DISCUSSION

DR. J. C. MORRELL (Universal Oil Products Company, Chicago, Ill.): I would like to ask Professor Stansfield to give me his experience on the relative merits of the roll and plunger type of presses. Would he apply one or the other to any given condition, also what condition would cause sticking in the plunger type and what remedy would be used to avoid this sticking

PROFESSOR EDGAR STANSFIELD: I am sorry that Mr. Lang is not here. He could answer these questions better than I can. It is difficult to compare these two presses because you cannot operate them under identical conditions, and our work is experimental and not on a large scale. On the whole, briquettes made with the plunger press were denser than those made with the roll press, but sometimes the results are reversed. We cannot very well compare the briquettes in the rattler, because the briquettes made in the plunger press are large and have sharp corners, while those made in the roll press are small and rounded but have a friable fin. In other words, the rattler tests are not comparable on the two different shapes of briquettes.

In answer to your other question with regard to the sticking. This is largely a question of moisture. The dry batch is more sticky than the wet batch. Cooling the mixture to a lower temperature sometimes avoided sticking where this would have occurred at a higher temperature. In brief, it is largley a question of temperature, moisture and binder.

JOHN L. EIGENBROT (General Coal Company, Philadelphia, Pa.): Regarding Dr. Soule's paper, it occurred to me that the gas being evolved in the inner cylinder might be different than the gas being evolved in the outer cylinder. If that is true, I should like to know what the characteristic difference is in these two gases and how they are handled, particularly whether separately or not.

Another question that occurs to my mind is what character of coal would be suitable for your process, that would not be suitable for your process, that would not be suitable for the standard forms of high temperature carbonization, and, with respect to the coke product, what is the apparent and real density of the typical coke produced?

DR. R. P. SOULE: In regard to the nature of the gas evolved in the inner drum, it is impossible, owing to the construction of the retort, to get gas samples from the inner drum independently of the outer drum. In fact, it is impossible to make an accurate determination of the temperature of the fuel leaving the inner drum, but inference, based upon the metal temperature determined from the over-all expansion of the inner drum, shows that it is very unlikely that the temperature of the coal leaving the inner drum and falling into the outer is in excess of 600°F. Under those conditions, it is not likely that there would be much of a gas evolution in the inner drum other than water vapor. It is a drying and preheating operation rather than a distilling operation.

So far as the nature of the fuels available for the K.S.O. retort is concerned, it is not intended that a wider variety will be available for that purpose than in the conventional gas generating equipment.

In regard to the density of semi-coke, that varies a little, depending upon the particular sort of coal that is used and also upon the manner in which it is handled. The density I suppose will be around 25 pounds per cubic foot, although figures both higher and lower have been obtained.

As to what the real density is, I am sorry that I cannot answer that question.

MR. EIGENBROT: I should like to know whether you have learned in subjecting coal to this temperature of 600° if it has any effect upon the swelling tendencies of the coals.

DR. SOULE: Yes, it has a very profound effect upon it Without the preheating and the sudden rise in temperature in passing into the second retort it would be impossible to obtain dense semi-coke and also to keep the lumps within reasonable size. They would become too large and clog the discharge mechanism.

COMMERCIAL ASPECTS OF LOW TEMPERATURE COAL DISTILLATION BY THE INTERNATIONAL BITUMENOIL CORPORATION PROCESS

By J. N. Vandegrift

Research Engineer

Bituminous Coal Problems and Possibilities

This is an era in which the engineering spirit is being broadly applied to the solution of civic and economic as well as industrial problems, including bituminous coal which during past several years has comprised, with agriculture and textiles, the "lame-duck" trinity of American industry. We have heard much of political and legislative relief for agriculture and textiles, but leaders of the coal industry are not seeking artificial remedies to adjust a war stimulated production capacity which remains far in excess of normal demand. Either high cost production mines must be discontinued and operatives diverted to other employment or new uses and demands for coal created to restore and maintain prosperity to the industry. And resourceful leadership will prefer the latter alternative.

In this connection the conversion of the low priced raw coal with limited demand into more valuable by-products, applicable not only to present but varied new uses in a much wider field, is the logical economic solution. Low temperature distillation presents a means to this end which is receiving most serious consideration at this time, and much interesting and encouraging research and development work was described in papers presented at the First International Conference on Bituminous Coal. In this article it is not proposed to offer the only method of treating profitably all classes of carbonaceous materials for all purposes but the commercial significance of results obtained from treating certain classes of coals and other materials in apparatus having an exceptionally flexible range of heat treatments and means of fractionational condensation of volatile products.

By converting most of the volatiles of bituminous coals into oils, tars and rich gas it is possible for the central power plant in many localities whether at the mine or market, to cheaply generate electric power derived from the smokeless fuel residue obtained at no cost, as the sale of the other by-products should ordinarily cover the cost of

the raw coal and processing of the many coals available for such a carbonization plant.

"If we can keep power abundant and cheap, we may hope to abolish poverty and win the good life for all," aptly expressed a worthy ideal in the paper by Messrs. John Hays Hammond and F. G. Tryon read before the First International Conference on Bituminous Coal. And in the production of cheap, abundant power at a profit, abating at the same time the smoke nuisance in industrial cities and centers, low temperature distillation seems destined to play a leading part.

United States Fuel and Power Resources

Coal is much more widely distributed than dependable water power in large volume, being found in thirty-six of our forty-eight states, while 80 per cent of our available water power lies between the Rockies and the Pacific where it is at present least needed. To make coal available in smokeless form as a general source of cheap power is of prime importance not only to the coal industry but to our social and economic progress. A prosperous people will soon insist upon a healthful smokeless atmosphere, made possible by smokeless fuel, aside from the loss incurred from damage to merchandise by a smoke laden atmosphere. The New York Merchants Association stated that this damage, in the Metropolitan district, averages $17.00 annualy per capita. This amounts to $170,000,000. And New York is not the smokiest city in the country. The much discussed hydro-electric power situation is not the solution to this problem. Former Secretary Hughes has reminded us that of the 190,000,000 horse power now required for transportation, industrial and domestic uses, only 6 per cent is furnished by water power; and that if the entire water power resources of this country are developed in the next thirty years they will furnish but 25,000,000 horsepower or only 6 per cent of the 400,000,000 horsepower estimated as needed at that time. And the smoke nuisance will be twice as serious as at present unless abated.

A continuation and expansion of our national prosperity will doubtless bring rapidly increasing use of oil burners for domestic heating for which there is a potential demand, according to authoritative estimate, of at least 250,000,000 barrels of fuel oil per annum. This would bring our total oil consumption in excess of one billion barrels. As the United States possesses one half of the world's coal

supply and only one twelfth of the known reserves of pertroleum it emphasizes the importance of making coal and its by-products available in the form of smokeless fuel, as well as oil, for domestic as well as industrial purposes. The time is approaching when the householder who cannot afford oil heating will at least insist upon replacing smoky bituminous coals with smokeless semi-coke in lumps of convenient domestic sizes. And low temperature distillation such as we have under consideration, makes these available in most cases without the expense of briquetting.

Our well known petroleum reserves, placed by the Federal Oil Conservation Board at six billion barrels by present methods of recovery and a problematical reserve of twenty-five billion barrels by more expensive methods to be developed, do not justify us in the midst of our present high rate of oil production and depletion in neglecting our second and third oil reserves—oil shales of which at least one hundred billion tons are apparently workable and, most important of all, our third line reserve of four trillion tons of coal, including bituminous, sub-bituminous cannel and lignites. And the key to these second and third line oil and fuel reserves is low temperature distillation. For profitable exploitation however, at this time in this country, it seems expedient to bring in the third or coal reserve before the shale.

Low Temperature Carbonization Materials

In certain contries and circumstances it may be profitable to consider liquefaction of coal by hydrogenation even at extremely high pressure and costs, or the catalytic conversion of coal gases into hydrocarbon oils or the maximum gasification of coals. In this country, however, it would appear more profitable in general to employ a continuous process at relatively low temperature, at approximately atmospheric pressure, with hydrogenation and catalysis as incidental features. The operation for nearly two years of a semi-commercial plant embodying these features has shown such evidence of durability and efficiency in recovering high quality oils, high B.t.u. gases, smokeless fuels and other by-products from a wide range of carbonaceous materials that profitable operation is apparently assured in the large scale treatment of at least part of these products.

The materials treated included bituminous, semi-bituminous, sub-bituminous and cannel coals, lignites, peat, Brazilian Turfa, Chilean,

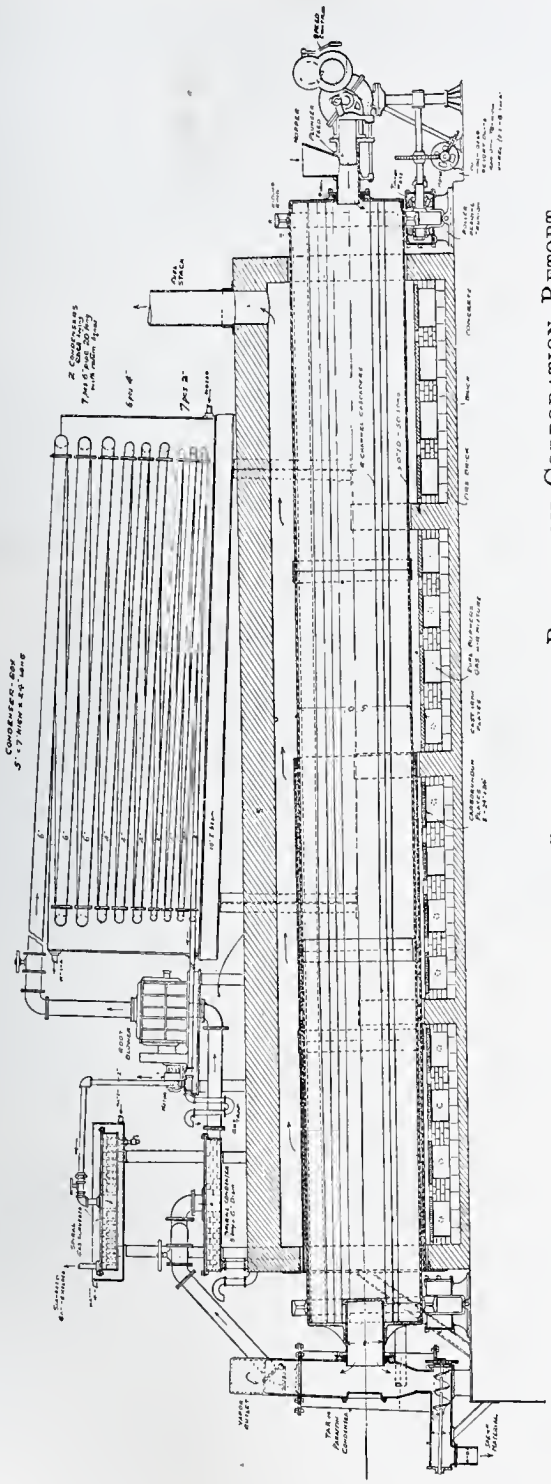

Fig. 1. Longitudinal Section. International Bitumenoil Corporation Retort

Esthonian, French and Italian shales and schists; likewise American shales from Colorado, Kentucky and Tennessee and oil sands from Missouri and California. The coals were received from Canada, England, Germany, Pennsylvania, West Virginia, Kentucky, Tennessee, Illinois, Oklahoma and Texas. This work by the International Bitumenoil Corporation has been under the general management of Mr. J. A. Vandegrift. The testing plant has been in daily service at New York under the supervision of the writer with Mr. Carl Postel as mechanical operator.

Successful treatment of such a wide range of carbonaceous materials in the same retort and condensing apparatus naturally implies a complicated equipment. In truth, however, the mechanism is of the simplest character—a result attained by a policy established through several years development of eliminating the superfluous and making each part perform as many functions as possible as long as the primary purpose of design was not impaired.

Low Temperature Treatment

In this way an inclined rotating tubular retort, designed primarily for low temperature distillation only, has been made likewise to dehydrate as well as hydrogenate, to carbonize and to apply treatment to prevent agglomeration or sticking of domestic sized lumps and fines or slack of bituminous coal particles to each other or to the walls of the retort. Accurate zoning of the heat in separate furnace compartments along the tubular retort, together with varied and novel methods of withdrawing vapors, introducing gases, feeding and discharging material, condensation of volatile products, air-sealing and other features, resulted in methods and apparatus conveniently flexible and adapted to widely varied treatments and results in processing the great variety of materials mentioned.

Within the limits of this paper it is impossible to present in detail the treatment of these products or the chemical and thermal reactions which may take place. Attention at this time is invited more particularly to the economic and commercial results obtainable from the use of the process and equipment for which contracts have been closed for extensive scale operation in this and foreign countries. It may be stated, however, that the zoning of heat along the inclined rotating tubular retort ranges from 500° to 700°F. in the two preheating zones and 900° to 1,100°F. in the fourth or carbonizing zone with intermediate temperatures in the third or intermediate zone. The firing

of the air-gas mixture in each of the four firebox chambers is through ducts arranged transversely and capped with carborundum or metal plates so that only burnt gases contact with the steel shell of the retort, thus preventing scaling and rapid deterioration without resorting to calorizing or expensive alloy steel construction.

Heat economy is effected by the longitudinal travel of the burnt gases released from each transverse flue, along the retort within the

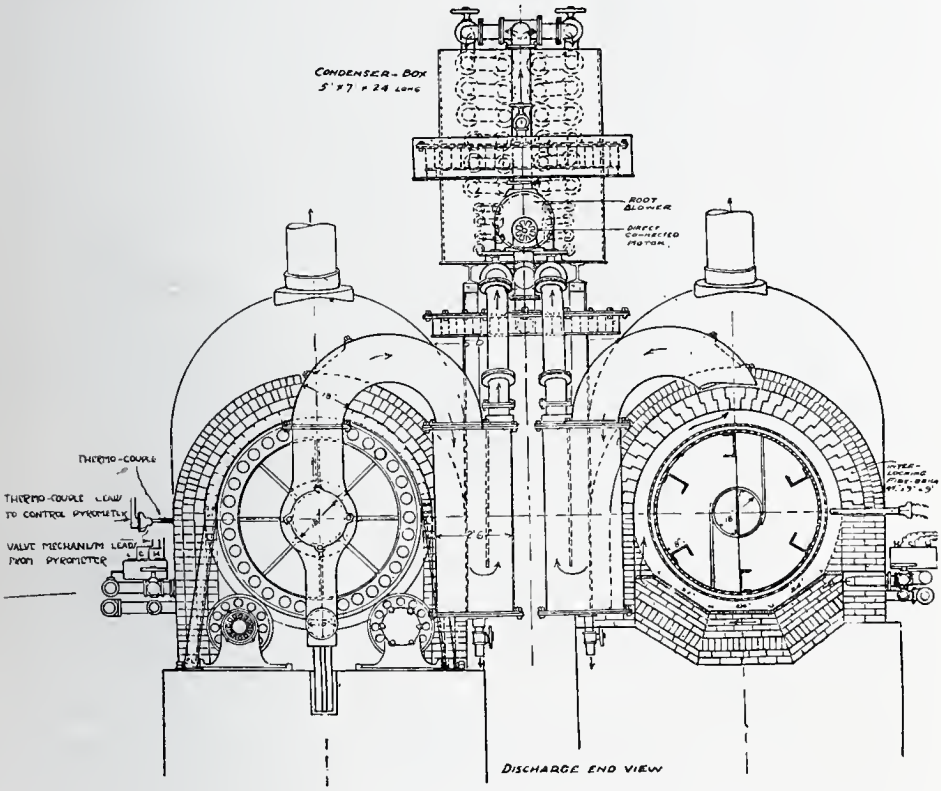

FIG. 2. END VIEW OF 200-TON TWIN UNIT INTERNATIONAL BITUMENOIL CORPORATION RETORTS AND CONDENSERS

upper part of the arched fire-brick furnace, requiring a relatively small amount of live gas-air mixture from the thermostatically controlled burners under the low temperature zones of the retort nearest the feed end. In the treatment of coals less than 2,000 cubic feet per ton of the 6,000 to 8,000 cubic feet of high B.t.u. gas ordinarily recovered is used in retorting; the surplus being available for sale or gas-electric generation of power.

In treating coking coals principles were followed which have been

used successfully in treating coal briquets. More than twenty years ago in New Jersey and elsewhere coal briquets with tar, and later with heavy crude oil binders, were heated in ovens to about 500°F. in the presence of air without setting up combustion and giving a very thin skin hardening or oxidation which prevented their agglomeration when subjected to higher temperature carbonizing treatment. Similar methods have been applied to the "Bitumenous Process" retorting of raw coals in both lump and powdered form. Air treatment however, was found unnecessary in retorting most coking coals, hot inert gases accomplishing better results in giving denser, heavier semi-coke in domestic sizes without the expense of briquetting.

In the International Bitumenoil Corporation Process heat zoning is ordinarily regulated to reduce the volatile content of the coke to about eight per cent, thus giving a smokeless fuel comparable to anthracite, but requiring somewhat less draft and which may be readily banked overnight. For industrial and power plant purposes, where powdered fuel is desired, the coke fines below domestic sizes may be pulverized. In the treatment of a given coal, heat zoning may be regulated to produce a maximum of gas and minimum of oil and tar according to market requirements.

BITUMENOIL PROCESS RESULTS

As an example of varying results in heat application in two types of retorts the following instance may be of interest. A German non-coking coal treated in a vertical stationary retort with internal firing and maximum temperature of 1,200°F. yielded 23 gallons of heavy tar and 14,000 cubic feet of gas per ton. Treated in the "Bitumenoil Process" retort, with heat zone temperature from 600° up to 1,000°F. the recovery was 49.3 gallons of oil with a relatively small pitch fraction, and 5200 cubic feet of gas per ton. The oil vapors largely released in the maximum heat zone, were immediately withdrawn by slight suction without extended travel or secondary decomposition into fixed gas in a hotter zone. If desirable to increase the gas and reduce the oil recovery to the vertical retort figures it can be done by changing the zoning of the heat in the tubular retort so that hydrocarbon vapors would be released in the third instead of the fourth zone in which case the lighter volatiles would be decomposed into fixed gases in passing through the fourth or hottest zone.

In the table of average recoveries (Table I), unless otherwise noted, the oils were recovered semi-refined in three separate fractions in-

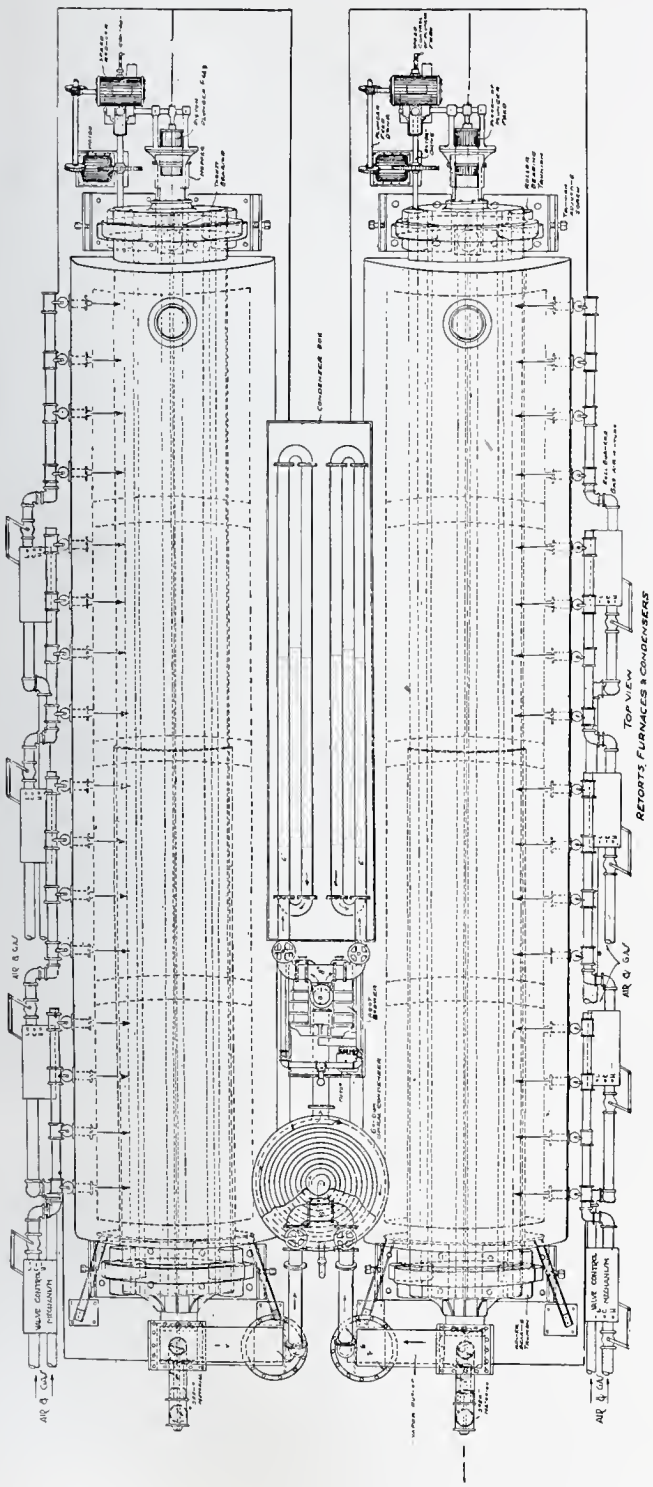

FIG. 3. TOP VIEW OF 200-TON TWIN UNIT RETORTS AND CONDENSERS OF INTERNATIONAL BITUMENOIL CORPORATION

TABLE I

INTERNATIONAL BITUMENOIL CORPORATION—AVERAGE RECOVERIES PER TON (2,000 POUNDS) AT NEW YORK TESTING PLANT

MATERIAL TREATED	TAR AND OILS	WATER	GAS HIGH B.T.U.	CARBONIZED RESIDUE	VALUE PRODUCTS PER TON	COST OF MATERIAL AND TREATMENT 400 TONS MIN.	NET PROFIT ESTIMATED PER TON	REMARKS
	gallons	*gallons*	*cubic feet*	*pounds*				
Alberta Coal, sub-bituminous..	26.5	20.0	3,400	1,450	$7.84	$3.75	$4.09	
Canadian Lignite.....	18.4	45.6	4,640	1,248	6.82	4.35	2.47	Lignite briquets @ $8.00 per ton
Texas Lignite.....	27.0	47.0	9,000	910	5.90	4.25	1.65	Lignite briquets @ $6.00 per ton
Illinois, Canton No. 5 Coal....	27.0	25.6	8,800	1,130	6.32	3.72	2.60	Smokeless fuel in domestic sizes, no briquetting
Oklahoma Coking Coal.....	22.0	15.6	6,400	1,380	6.72	3.75	2.97	Smokeless fuel in domestic sizes, no briquetting
Pennsylvania Coking Coal.....	26.3	3.2	6,300	1,434	6.97	3.95	3.02	Coke briquets $6.00 per ton
Pennsylvania Cannel Coal.....	29.8	10.9	4,080	1,474	7.12	4.60	2.52	Includes topping and refining gasoline
Tennessee Coking Coal.....	25.6	17.0	6,000	1,410	6.20	3.40	2.80	
Tennessee Cannel Coal.....	62.5	19.4	7,000	1,000	8.25	4.90	3.35	Includes topping and refining gasoline
Kentucky Coking Coal.....	26.0	21.25	6,000	1,324	6.60	3.72	2.88	Coke briquets $6.00 per ton
Kentucky Cannel Coal.....	39.3	15.00	5,500	1,275	7.80	4.85	2.95	Includes topping and refining gasoline
British Coking Coal.....	16.0	33.14	6,508	1,284	7.40	4.35	3.05	Smokeless fuel not briquetted
German Non-Coking Coal.....	49.3	35.6	5,209	1,060	8.15	4.50	3.65	Semi-coke briquetted
Brazilian Turfa.....	104.0	45.0	6,200	498	12.25	4.50	7.75	Refining Gasoline and Lubricating Oil at Plant

Chilean Shale	42.4	3.2	6,760	1,306	9.40	4.60	4.80	Refining Gasoline and Lubricating Oil at Plant
Esthonian Shale	56.0	10.0	4,800	1,232	9.20	4.75	4.45	Refining Gasoline and Lubricating Oil at Plant
Italian Shale	24.0	9.0	3,800	1,546	5.50	3.75	1.75	Refining Gasoline and Lubricating Oil at Plant
Colorado Shale	43.0	5.0	5,800	1,638	5.00	2.85	2.15	Marketing Lubricating Oil and Gasoline Refined at Plant
California Diatom	41.5	13.5	4,920	1,314	10.62	5.81	4.81	Marketing Light Oil, Flotation Oil and Diatom

Note: The results above tabulated were obtained in a "Bitumenoil Process" inclined rotating externally heated retort 10 inches diameter by 10 feet long of 2 tons capacity per 24 hour day.

cluding first, pitch or paraffin in volume 5 to 15 per cent of the total; second, medium and heavy oils 60 to 70 per cent of the total; and third light oils 15 to 30 per cent of the total, the latter comprising largely motor spirit fractions such as benzol and gasoline. In making initial installations of small commercial plants of less than one thousand tons daily capacity, it will doubtless be preferable to market these semi-refined oils as they come from the fractionating condensers rather than incur the capital investment of a refining plant to market an extended list of oil and coal-tar products. These oils will ordinarily bring

TABLE II

Receipts per ton of cannel coal treated:		
17 gallons motor spirits @ 10 cents	$1.70	
33 gallons medium oils @ 6½ cents	2.15	
10 gallons semi-solid residue @ 4 cents	0.40	
5,000 cubic feet 800 B.t.u. gas @ 30 cents	1.50	
1,000 pounds smokeless fuel @ $5.00 per ton	2.50	
Receipts per ton		$8.25
Expenses per ton:		
1 ton cannel coal at mine	$2.00	
Freight to plant	1.00	
Crushing, retorting and condensing	0.50	
Topping and refining motor spirits	0.45	
Piping and delivery	0.10	
Plant Amortization (10 years)	0.25	
Taxes, etc	0.10	
Overhead and sales expense	0.50	
Expenses per ton		$4.90
Net income per ton		$3.35

Estimated cost of 400 ton plant, $300,000.

from six to eight cents per gallon and are recovered by the "Bitumen-oil Process" in amounts ranging from about 20 to 60 gallons per ton in treating coals available for profitable processing. The surplus gas available for sale will ordinarily be sold at about thirty cents per thousand to the local public utility corporations. The carbonized smokeless fuels, unless otherwise noted, were recovered in domestic sizes without briquetting and may be marketed somewhat below the wholesale price of anthracite or at the rate of six to eight dollars per ton. The fines at a lower rate for powdered industrial fuel, or in

some instances briquetted for domestic purposes, should average for the entire solid fuel recovery at least five to six dollars per ton.

It may be noted that the largest oil recovery from coal, 62.5 gallons per ton, was obtained from Tennessee cannel. This oil was a petroleum, largely of paraffin base, and in addition to 7,000 cubic feet of 800 B.t.u. gas the coal yielded one-half ton of smokeless fuel in domestic sized lumps of firm solid structure, the same size as charged. It offers such attractive commercial possibilities that a detailed estimate of revenues, operating expenses and net receipts is presented herewith in Table II. The total oil recovery, with a topping cut, and no attempt at cracking, yielded 28 per cent or 17 gallons per ton in gasoline. With cracking at least 35 gallons per ton may be converted into

TABLE III

ESTIMATED REVENUE FROM BITUMINOUS COAL

Gas—4,000 cubic feet—800 B.t.u. per ton @ 30 cents	$1.20	
Oil—25 gallons per ton @ 6 cents	1.50	
Fuel, 1,300 pounds per ton @ $6.00	3.90	
Gross Revenue per ton of coal		$6.60
Cost of coal at mine (slack)	$1.25	
Crushing, retorting, condensing, briquetting and delivery	$1.87	
Depreciation of Taxes	0.30	
Overhead and selling	0.40	$3.82
Net Profit per ton		$2.78

gasoline. This compares favorably with average well petroleum. Additional revenues from gas and smokeless fuel bring estimated net receipts to $3.35 per ton on the basis of an initial installation of two twin retort-condensing units of 400 tons total daily capacity.

As the net income per year of 300 days operation is, on this basis, in excess of the cost of plant installation a radical reduction in the current prices obtainable for products is possible without the prospect of unprofitable operation.

In Table III is presented an estimate of revenue and expenses in commercial plant operation with a minimum of four one hundred ton retorts which will show in general the basis upon which results were arrived at in a number of coals listed in Table I. Where briquetting of coked residue into domestic fuels is unnecessary, as with most coals

treated, the operating costs are reduced by nearly one dollar per ton. In Table III, the oils and tars are not treated as refined products.

THE LOW TEMPERATURE CARBONIZATION FIELD

An inspection of Table I, indicates that in the United States a profitable field, at this time, for low temperature carbonization lies along the Appalachian Range in the treatment of high volatile bituminous and cannel coals. Likewise in the Illinois and Oklahoma regions. Lignites are also worthy of serious consideration not only in Texas but particularly in North Dakota, and Canada, and in the latter country the sub-bituminous coals of Alberta may be treated, preferably at plants located at the place of consumption of gas and smokeless fuels. The enormous deposits of sub-bituminous coals in our western and northwestern states may warrant plant installation at this time where mine and market are relatively near.

In general initial plant installation may be more advantageously located at towns affording markets of considerable size and located within 50 or 60 miles of the mine, or at about a dollar per ton freight rate on coal. Such an initial plant should be of at least 400 and preferably 1,000 tons per 24-hour day capacity and preferably dispose of its gas to the local public utility corporation and smokeless semi-coke to dealers or truck it directly to consumers. The coal tars and oils will be shipped by tank-car to the tar by-product or the petroleum refinery in the case of paraffin base cannel oils. Obviously the plants located in sections distant from anthracite or natural gas fields will be at an advantage, other considerations being equal.

There has been much discussion in recent years of the advantages of the super-electric power plant located at the coal mine. Increasing voltages and long distance transmission make this possible in a multiple hook-up of towns and cities within two or three hundred miles. Increased national prosperity means not only rapidly increasing demands for industrial and domestic power and light but for the large-scale electrification of steam railroads between populous centers now planned for both passenger and freight service such as that of the Pennsylvania Railroad between New York and Wilmington, Delaware. Low temperature carbonization may furnish not only the smokeless fuel, preferably in pulverized form, for power generation but a high B.t.u. gas worthy of long distance piping to various public utility plants. For some time to come however, we are not likely to equal the 450 miles of gas piping from the Ruhr to

Berlin. The coal oils and tars, refined into motor spirits and a lengthening list of tar by-products should find broader and larger markets with increased quantity production of power fuels.

These are not merely possibilities, but probable trends following the inauguration of the low temperature carbonization industry, the ultimate scope of which it is idle to predict. The point is that results obtained in apparatus of demonstrated durability and efficiency indicate that it is profitable to start the industry in this as well as foreign countries with present market prices of recoverable by-products. Responsible British interests have contracted for a plant in England of 2,000 tons daily capacity with 600 tons initial installation of the International Bitumenoil Corporation Process and American interests are starting a smaller installation in Tennessee. Their commercial success, with that of other well designed processes and installations, it is hoped will help to establish this means of expanding the bituminous coal industry, central power plants and public service in general.

SOME FUNDAMENTALS OF THE CARBONIZATION OF CAKING COALS: THE FORMATION OF CENOSPHERES

By F. S. Sinnatt

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Read by Dr. C. E. Evans

The investigation of the structure and properties of coke in relation to the qualities required for industrial purposes is an important and difficult problem. Information on the properties must, in the end, undergo the acid test of being correlated with the industrial uses of the coke, and as a rule such investigations have been carried out in association with some industrial process. This presupposes concentration upon some particular quality or qualities of the carbonized residue somewhat to the neglect of generalizations. Coke, or the solid residue from the carbonization of organic matter, in one form or another, is probably the most important manufactured product in commerce, and many varieties are required to satisfy the needs of industry. Electrode carbons, charcoals, graphites, lamp black, active charcoal are made in relatively large quantities, while immense quantities of metallurgical, foundry, and gas coke have to be manufactured. Some 50 million of tons per annum are required in the United States and 20 million of tons in Great Britain, and in addition the low temperature coke industry is now passing into the manufacturing stage. Each of the above cokes or carbons must possess certain essential qualities to make it suitable for particular industrial purposes. The factors which determine the hardness, combustibility, reactivity, etc., of the cokes are extremely complicated, and a greater store of fundamental data is required if the problems encountered in the coking industry are to be solved.

It appears desirable to call attention to a recent paper Professor Wheeler delivered before the Deuxième Congress Chauffage Industriel, in which he shows that carbon produced by the decomposition of methane is not mainly a brilliant glistening variety, as usually supposed, and that a dull, soft variety is not necessarily obtained by the decomposition of ethylene. Both forms of carbon and a form intermediate in character between the two can be produced from both hydrocarbons, the condition of the carbon depending on the character of the heated surface over which the gas is passed, the rate

of passage of the gas and the temperature of decomposition. There is little difference between the two varieties and both are much less reactive than either natural or artificial graphite, as Table I shows.

The object of the present paper is to call attention to certain aspects of the structure of coke as observed when particles of caking coal are carbonized. It is proposed to deal with some special aspects of the problem, and to place some emphasis upon the structure of coal seams in relation to the question of the structure of coke.

Coke is heterogeneous in character, and the complexity of a particular sample depends upon the type of fuel or blends of fuel carbonized, and the temperature, rate and method of carbonization. Coal and coal seams possess a banded structure which is of primary

TABLE I

RELATIVE RATES OF REDUCTION OF CARBON DIOXIDE AT 1000°C. BY DIFFERENT VARIETIES OF CARBON

	VARIETY OF CARBON	RATE OF REDUCTION
1	Glistening (from methane or ethylene)	1
2	Dull (from methane or ethylene)	1.2
3	Natural graphite	19.1
4	Artificial graphite	29.6
5	Spruce fir charcoal	530.7

importance in considering the properties of coke. White and Thiessen in the United States, and Stopes, Seyler, Wheeler and Lessing in Great Britain, have done much to indicate the significance of the ingredients or layers in coal seams, but the commercial application of the data requires closer attention. Dr. Thiessen in the United States has identified three main ingredients in coal seams which he has termed anthraxylon, attritus, and fusain, while Dr. Marie Stopes distinguishes four ingredients in British coals, viz., Vitrain, Clarain, Durain and Fusain. These distinctions are convenient, and refer to ingredients possessing certain palaeobotanical features which can be associated with broadly similar coking and other properties in a particular seam. They may give rise to a false impression by suggesting that the ingredients are uniform in properties; clarain for example, a caking or coking ingredient in many British seams, may vary in its properties in different layers in the same seam. The narrow layers in a seam may differ in such characteristics as (*a*) caking properties, (*b*)

chemical composition, and (*c*) quantity and composition of the ash, etc., although each layer may be designated Clarain. This diversity in properties of the layers must be thoroughly appreciated if coke possessing the maximum qualities for a particular process is to be produced from a particular seam or blend of seams. Some years ago

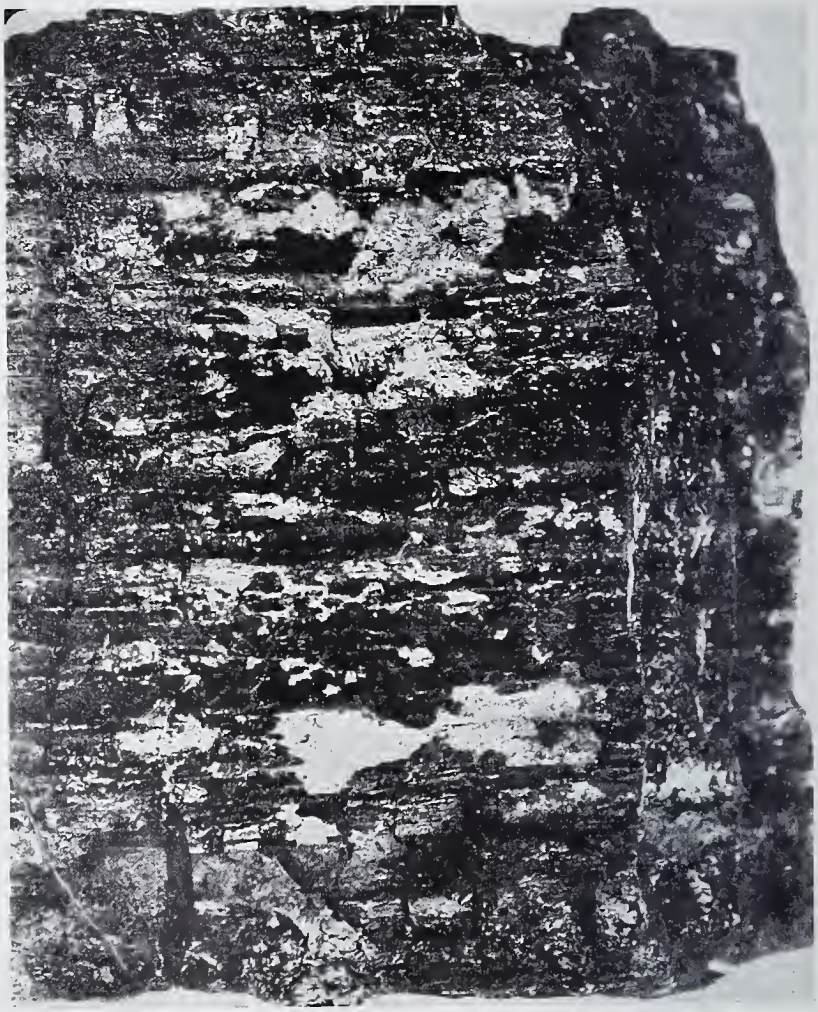

FIG. 1. PHOTOGRAPH OF PIECE OF COAL SHOWING THIN BANDS (ACTUAL SIZE)

the writer determined the number of layers each of greater thickness than $\frac{1}{32}$ inch in a series of coal seams, and found 91 layers in a seam 33 inches thick, 155 in a seam 51 inches thick, and 150 in one 70 inches thick. No figures are available for the actual number of thin layers in a seam. The number can be judged by an examination

of Figure 1 which is a photograph of a piece of coal. The layers which can be distinguished are composed of the debris of plant entities, and

FIG. 1A. X-RAY PHOTOGRAPH (TWO-THIRDS ACTUAL SIZE)

each may differ widely from its neighbor in certain characteristics. A further illustration of the differences in the layers is found in Figure

TABLE II

THE BANDED CONSTITUENTS OF COAL

BAND NUMBER	CHARACTER	MOISTURE	ASH ON DRY COAL	CHARACTER OF ASH	
				Ferric oxide in coal	Ferric oxide in ash
		per cent	*per cent*	*per cent*	*per cent*
1	Clarain, a little durain	1.82	9.25	0.69	7.5
2	Vitrain	1.78	6.42	0.79	12.4
2a	Vitrain	2.04	4.88	0.90	18.4
3	Vitrain, a little clarain and fusain	1.80	5.23	0.98	18.7
4	Durain, with vitrain	2.04	7.88	0.292	3.86
4a	Durain, with more vitrain	2.01	7.04	0.78	11.0
4b	Durain, with more vitrain	2.12	7.03	0.48	7.05
5	Clarain, a little fusain	1.97	3.30	0.44	13.5
7	Vitrain and clarain finely interlayered	2.20	2.81	0.511	18.6
8	Durain, some bright coal streaks	2.02	5.16	0.299	5.8
9	Durain, more bright streaks	1.91	2.65	0.243	9.2
10	Clarain, some vitrain, little fusain	1.91	4.92	1.19	24.6
11	Vitrain	2.14	4.53	1.08	24.0
11a	Vitrain	2.60	3.13	0.93	30.0
12	Clarain	2.00	3.98	0.85	21.2
12a	Vitrain and clarain, finely interlayered	2.07	5.37	1.24	23.0
13	Clarain and vitrain, pyrites	2.00	11.31	3.83	30.7
14	Vitrain, clarain and little pyrites	2.10	4.29	0.71	16.4
15	Clarain	2.27	4.87	1.06	21.1
16	Clarain and pyrites	2.32	8.22	2.04	24.7
16a	Clarain and pyrites	2.20	6.08	1.24	20.3
17	Vitrain	1.73	4.07	1.08	23.0
18	Clarain	1.99	6.75	—	—
18a	Vitrain and clarain	1.76	5.10	0.91	17.9
19	Vitrain	1.86	5.60	1.51	26.9
20	Vitrain and clarain	1.66	4.91	1.40	28.5
21	Clarain, little vitrain	1.69	3.20	0.73	23.0
	Fusain	1.65	6.30	—	—

1a, a photograph,[1] reduced to two-thirds actual size, taken by x-rays of a piece of the same seam. The coal, which was 8 inches of the thickness of the seam, was cut into a slab $\frac{1}{2}$ inch thick, and the layers

[1] C. N. Kemp, The X-Ray Examination of Coal Sections, *Proc. Roy. Soc. Edin.*, 1927–28, 48, 167.

seen in the photograph are the inorganic constituents present in the separate narrow bands parallel to the bedding planes. When the photograph had been obtained the actual piece of coal was carefully dissected, and the chief layers, indicated by numbers, of which 21 could be recognized, were separated and the percentage of ash present determined, together with the amount of iron. The results are given in Table II. The results show the great variation in the amount of ash present, and the fundamental differences in composition as can be judged by the percentage of iron. Lessing and Cobb and their associates (J. Soc. Chem. Ind., 1925, *44*, 345; Trans. Inst. Gas Engineers 1926–1927, p. 333,) have proved conclusively that the inorganic constituents have a profound influence upon the yield of products obtained during carbonization, and also upon the structure and properties of the coke obtained. In view of this each individual layer in the above typical piece of bituminous coal may yield coke possessing definite characteristics, and quite distinct from its neighbor. It may be suggested that these considerations are of little importance in relation to lump coke which before it is formed passes through a plastic mass, and is a composite material, but they become of great moment in considering the blending of coal and the treatment the coal must receive before it is charged into the oven. In order to extract the maximum value from a coal seam it is necessary to grind it, probably to a critical size, and to blend it carefully with other seams, or if a single seam is being used, all parts must be brought together and thoroughly and carefully mixed. It is possible to obtain uniform and strong coke from a single seam by careful grinding and blending which otherwise yields uneven and weak coke. Some emphasis is desirable upon this statement, as it is frequently thought that because a single seam is being used crushing and blending are not necessary. It is just as important as when two or more seams are being used.

The great paucity of data upon the coking properties of the narrow layers of less than $\frac{1}{32}$ inch led the author in 1918 to commence a study of the effect of heat upon coal in the form of fine particles. The investigations have been carried out in association with three research assistants, Dr. L. Slater, H. E. Newall, A. McCulloch, and later with H. Leech and A. C. Maries, and the present paper is a summary of six papers giving details of the subject which have appeared in the British journals.

As far as can be ascertained, only two short publications deal with the structure of the solid product obtained by the carbonization or

combustion of particles of coal. Both investigations were carried out by the late Sir W. E. Garforth and Mr. H. Crowther, and a description of the experiments can be found in the Record of the First Series of the British Coal Dust Experiments, published by the Colliery Guardian Company, Limited, in 1910. Certain of the observations are contained in the evidence of the Royal Commission on Coal Dust in Mines, 1891. The results obtained by Garforth and Crowther are so remarkable that it is surprising to find that no effort has been made to continue their investigations. They found that hollow spheres

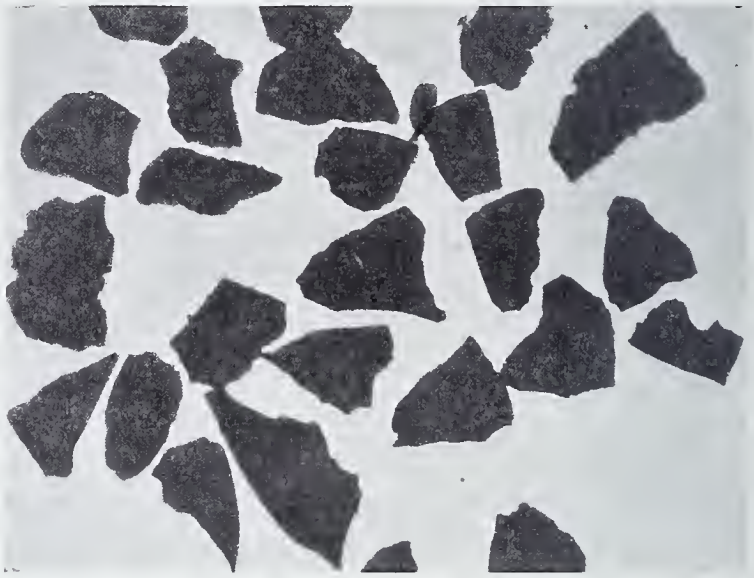

FIG. 2. PARTICLES OF COAL 60 TO 90 MESH, I. M. M. MAGNIFICATION ×45

of carbonized product were present in the dust collected after an explosion in a mine, and that similar bodies could be made by introducing coal dust into a blowpipe flame and partly carbonizing and burning the coal. The spheres were identical in structure with cenospheres.

At the last Bituminous Coal Conference held in 1926 Professor White dealt with the instantaneous carbonization of coal, and stated that his researches were commenced prior to the publication of a paper by Newall and the author in 1924, overlooking the fact that Dr. Slater, in association with the author, published a short paper on the same subject in *Fuel* in 1922, Vol. 1, page 2.

Although the results of the carbonization of coal in the form of fine

particles cannot at present be said to have a direct bearing on the structure of lump coke, the results are of direct interest in (*a*) the combustion of pulverized coal, (*b*) combustion of fine coal in ordinary furnaces, (*c*) the carbonization of pulverized coal (the McEwen-Runge process), (*d*) the carbonization of fine coal where free expansion

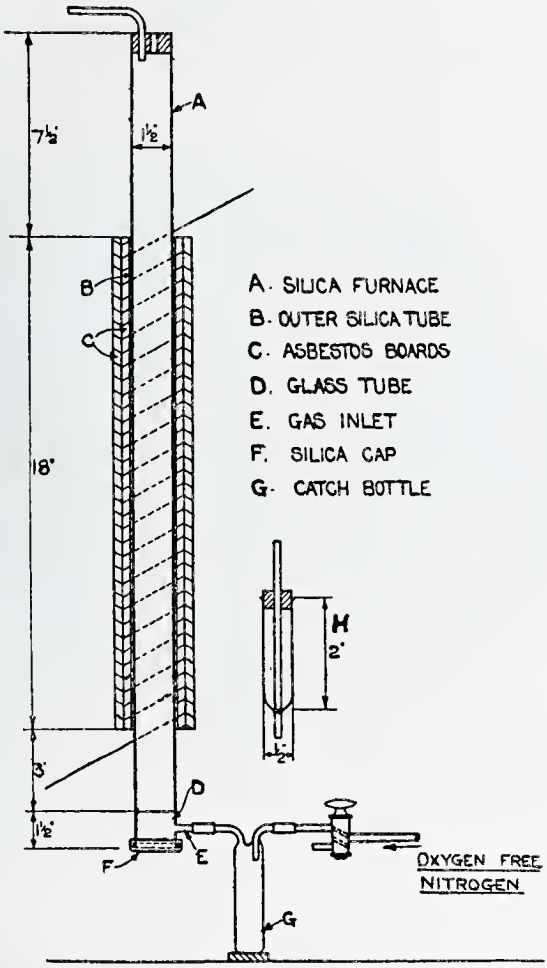

FIG. 3. DIAGRAMMATIC SKETCH OF APPARATUS (SMALL SCALE)

is possible, and (*e*) the carbonization of blends of caking and non-caking materials.

The carbonization of coal in the form of fine particles (Fig. 2) is a normal procedure in coke manufacture, but as the coal passes through a plastic stage the behavior of single particles cannot be clearly distinguished. The author has found that if finely powdered caking

coal is mixed with inert material and carbonized under carefully controlled conditions, small spheres of coke can be obtained, some of which are hollow. When the inert medium used is a gas and the particles of coal are allowed to fall into a heated tube, hollow spheres of coke are produced which have been named cenospheres.[2]

The experiments have been carried out in vertical tubes of various dimensions, from one made of silica 30 inches by $1\frac{1}{2}$ internal diameter (Fig. 3) with 18 inches of heated zone to a retort of cast iron 20 feet high. The small tubes were fitted with an inlet at the lower end for the introduction of nitrogen or other gases. The smaller tubes were heated electrically and the larger by gas. A predetermined temperature was established in the tube as recorded on the central axis with the tube closed at the top and bottom. In the larger tube 30 cwt. of

TABLE III

ORIGINAL COAL, VOLATILE MATTER 23.7 PER CENT

TEMPERATURE OF HEATING	NUMBER OF TREATMENTS DURATION OF HEATING PER TREATMENT BEING ABOUT 1 SECOND	VOLATILE MATTER IN HEATED DUST
°C.		*per cent*
420	12	23.40
420	18	23.10
500	12	22.00
530	12	17.50
580	6	13.62
620	6	12.20

cenospheres have been made in a day. Arrangements were made for dropping the particles of coal down the small tubes either as single particles, or as a dispersed cloud. It will be realized that the conditions are favorable to carbonization by radiant heat.

For the early experiments (*Fuel*, 1922. Vol. 1, page 2) a highly caking coal was selected. The coal was ground until the whole would pass a sieve of 200 mesh I.M.M. (orifices $\frac{1}{400}$ inch). The results of treating coal at a range of temperatures in the tube with 18 inches of heated zone are given in Table III.

After twelve treatments at 420°C. there was no change in the

[2] "Cenosphaera" has been previously applied to form of a sub-order sphaeroidea of the order spumellaria a minute single cell organism (diameter 0.09 mm.). The organism has a single shell composed of lattice with equal hexagonal meshes.

degree of fineness of the particles, and although the caking power was destroyed, the loss in volatile matter was only 0.6 per cent.

At 500°C. there was no change in the size of the particles, but the caking property was destroyed.

At 530°C. the particles were converted into spheres or globules, practically solid, slightly larger than the original particles, but the windows and lattice to be mentioned later could not be detected. The particles had in fact melted and formed practically solid spheres

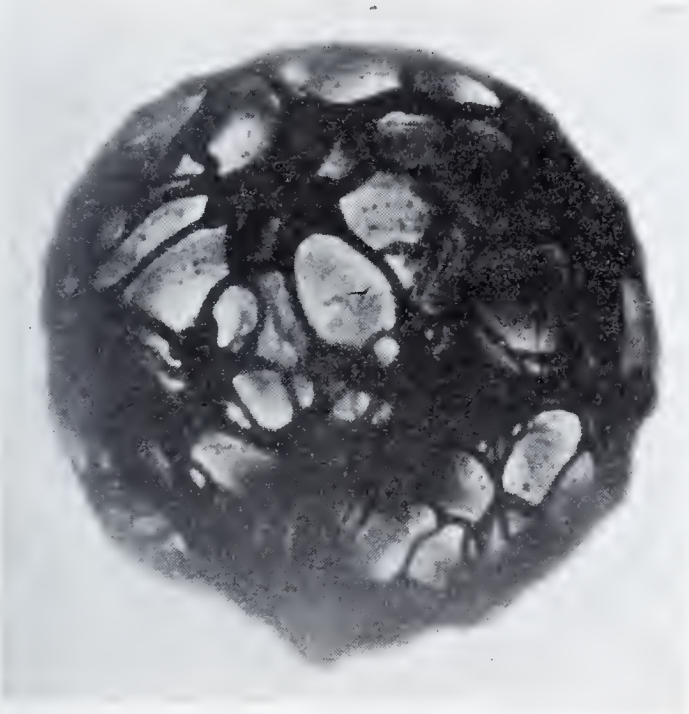

FIG. 4. CENOSPHERE. TEMPERATURE 700°. MAGNIFICATION × 120

of coke. The next experiments were carried out upon caking coals of various types sieved to pass a screen of $\frac{1}{60}$ mesh I.M.M. (orifice $\frac{1}{120}$ inch) and remain on a screen of $\frac{1}{90}$ (orifice $\frac{1}{180}$ inch) and the temperature in the tube was 600°C. The particles of coal were converted into hollow spheres, black and lustrous by reflected light with a surface irregular and broken up by minute pores and vesicles. Large areas of the hollow spheres are transparent when viewed by transmitted light, and the whole structure of a cenosphere is similar to an irregular open meshed hollow basket ball with the spaces covered by

a thin film (Figs. 4 and 4a). As a convenience the terms "lattice" and "window" have been applied to the structures. The window of the majority of cenospheres in the coals studied up to the present are dotted with irregularly placed minute forms, or specks, which have been designated the tertiary structure of coke. The specks can be seen in a window in Figure 5. A proportion of the cenospheres which varies with different seams does not exhibit the tertiary structure in the windows. The number of windows in cenospheres made from several seams under constant conditions was found to vary from 24

FIG. 4A. CENOSPHERES. TEMPERATURE OF CARBONIZATION 700°C. MAGNIFICATION ×45

to 104. The average number in one particular group of 500 was 50. The windows are not uniform in shape and although pentagonal and hexagonal forms predominate four and three sided figures are present. The method of formation is so complex that regularity of form cannot be expected, and although the characteristic structure associated with the formation of a foam has not been definitely recognized, every endeavor is being made to designate the structure of the bodies. The tertiary structure or specks have been counted in many windows, and in one case 230 were present in one window. It would, therefore,

appear possible for a cenosphere to have in its skin (or surface) some 10,000 specks of a material, the composition and properties of which are not known. The average diameter of the cenospheres in question was 0.5 mm. and the surface area 1.0 sq. mm. The average weight of particular cenospheres was about 2.0×10^{-5} gram, and consequently the weight of one of the specks to be seen in the windows was 2×10^{-9} gram. The facts cannot be dismissed as being of little practical significance because the properties of the surface of cenospheres depends upon these specks, and although they have not been detected

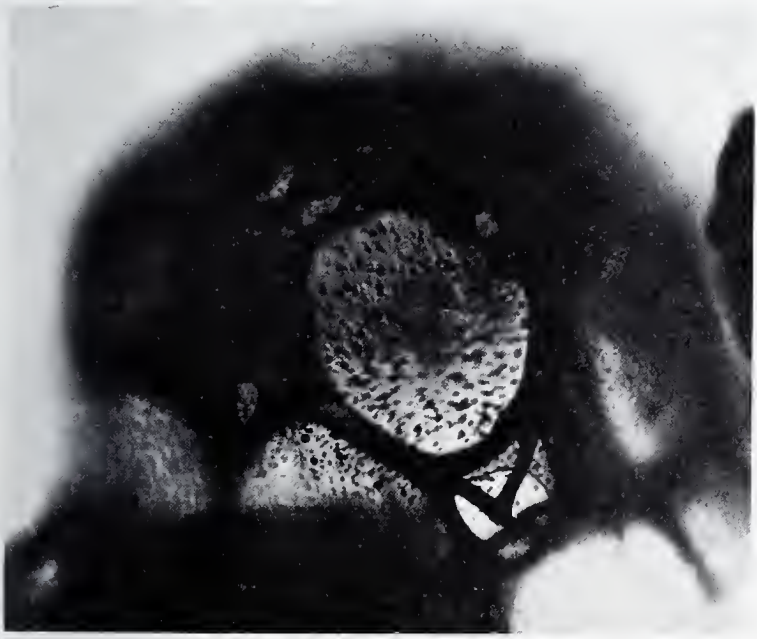

FIG. 5. TERTIARY STRUCTURE SEEN IN WINDOW. TEMPERATURE OF CARBONIZATION 650°C. MAGNIFICATION ×180

up to the present in coke, largely it is believed on account of the absence of a suitable technique, they must be explored in relation to the properties of coke.

The walls of a cenosphere are glasslike and form a complete envelope which is gas-tight, but gradually becomes permeable to liquids such as ether. Frequently the windows are corrugated owing to shrinkage on cooling and fissures may be detected from the same cause. The walls are distinctly elastic and the windows are frequently concave in shape owing to the decrease in the volume of the gas caused by the

cenospheres cooling, while if they are warmed the windows bulge owing to the expansion of the gas. The windows are extremely thin, and not uniform in thickness, the transition from lattice to window being gradual in some cases, and rapid in others. Diffraction effects can frequently be observed. The effects of the various carbonizing factors have been studied, and it has been found that when particles of 60 to 90 mesh are treated in the small tube at a temperature of 500° vitrain and clarain particles were converted into spheres possessing glassy lustrous surfaces. The particles had intumesced only very slightly. Durain particles retained their angular shape and matt appearance generally, although a number were slightly glazed on the

TABLE IV

INFLUENCE OF TEMPERATURE ON THE SIZE OF THE CENOSPHERES

	DIAMETER	INCREASE IN VOLUME
	mm.	*times*
Vitrain:		
Particles before carbonization	0.34	—
At 500°C	0.41	1.7
At 600°C	0.47	2.6
At 700°C	0.59	5.2
At 800°C	0.68	8.0
Durain:		
Particles before carbonization	0.34	—
At 500°C	0.35	1.1
At 800°C	0.43	2.0

surface; occasionally particles intumesced. It must be recognized that complete separation of the ingredients of coal is practically impossible.

At a temperature of 550° the appearances of the carbonized particles were similar, but the particles were larger in volume. Windows could not be detected. With durain the particles were spherical and swollen very slightly in the case of one seam; durain from other seams, and non-caking coals retained the original form of the particles.

At 600° it was found that vitrain and clarain behaved in an identical manner, and cenospheres with transparent windows were formed. With durain the particles were slightly glazed, but cenospheres were not formed.

The formation of cenospheres appears to be associated with a

definite increase in volume of the particles of coal from a particular layer in a seam. A number of experiments were carried out upon a particular coal seam at 525°, 550°, and 575°C., and it was observed that lattice and window structure could not be clearly detected until a temperature of from 570° to 600° was attained. This temperature is fairly definite for the coal taken under the conditions described in this paper. It may be considered to be a broadly-defined characteristic for the vitrain and clarain of coals. With an increase in the temperature, there is an increase in the size of the cenosphere, and it has been observed generally that the network of the lattice is at first close and the windows are small and highly colored or translucent; as the temperature is increased, the lattice becomes more open, and the windows larger. As the cenospheres increase in size, the windows and the lattice become thinner; no alteration occurs in the general form of the cenospheres, but the windows lose their brown appearance and become nearly colorless when viewed by transmitted light.

Measurements were made of the longest and shortest diameters of the coal particles and the cenospheres, and the average diameter was then calculated. It is obvious that the method cannot yield absolute values for the diameters of the bodies, and more especially for the coal owing to the irregular shape of the particles.

The change in apparent specific gravity of the cenospheres with increase in the temperature of carbonization has not been determined with accuracy. Approximate values indicate that when carbonized at 500°C., vitrain and clarain yield particles the specific gravity of which is about 0.8, while from durain the specific gravity is about 0.9. At 570° to 600°C. a few of the particles from vitrain and clarain had an apparent specific gravity of about 0.2. Durain, on the other hand, yielded particles having a specific gravity of 0.80 at 600°C.

Particles of vitrain, clarain, and durain were separated, carefully sized, and then carbonized under identical conditions at 600°, and the cenospheres measured with the results given in Table V.

The variation in size of cenospheres from accurately sized particles of coal was examined by treating particles caught between 50 and 60 mesh screens I.M.M. at 800°C. A specimen of clarain taken from every part of the seam was used in the experiments. Table VI contains the diameters of the cenospheres in millimeters, as measured in a group of consecutive determinations from a series numbering some thousands.

The variation in the size of cenospheres must be attributed to

differences in the properties of the particles of coal, and to variations in the size of the original particles of coal. As already stated, although extreme care was exercised in screening the coal, variation in the size of the coal particles was possible, due largely to the influence of the shape.

TABLE V

	AVERAGE DIAMETER	
	Seam A	Seam B
	mm.	*mm.*
Coal particles	0.34	0.34
Durain	0.35	0.34
Vitrain	0.47	0.39
Clarain	0.54	0.43

TABLE VI

DIAMETER	DIAMETER
mm.	*mm.*
0.55	0.34
0.58	0.45
0.28	0.60
0.49	0.62
0.65	0.22
0.58	0.40
0.76	0.70
0.42	0.57
0.53	0.22
0.56	0.57
0.60	—

	mm.
Maximum size (diameter)	0.76
Minimum size (diameter)	0.22
Average size (diameter)	0.55

It is believed, however, that the difference in volume in Table VI must be ascribed in a measure to variations in the swelling properties of the individual particles, since the conditions of treatment were maintained as constant as possible. The smallest particle has approximately the same volume as the original particles of coal, whilst the largest cenosphere is about 40 times the volume of the coal. The

average size of the cenospheres is about 11 times the volume of the original particles of coal. The result is of some commercial interest as an illustration of the great swelling and possibly covering power of a proportion of the layers in the coal seams. Clarain alone was used in the particular experiments, and when it was carbonized *en masse* in a crucible the coke produced was twice the volume of the original coal. The question arises of how to utilize the swelling properties of the individual particles to the maximum extent.

Experiments have been carried out to obtain information as to the minimum length of heated tube required to bring about the formation of cenospheres. The experiments were carried out by allowing the particles to fall under exactly similar conditions into a tube, the heated portion of which was extended downwards. The shortest length was 6 inches, and the longest 18 inches. The temperature

TABLE VII

EXPERIMENTS WITH THREE DIFFERENT LENGTHS OF HEATED TUBE. TEMPERATURE 600°C. AVERAGE DIAMETER OF PARTICLES OF COAL 0.34 MM.

LENGTH OF TUBE HEATED	AVERAGE DIAMETER		
	Vitrain	Clarain	Durain
inches	*mm.*	*mm.*	*mm.*
6	0.41	0.43	0.34
12	0.43	0.49	0.35
18	0.47	0.54	0.37

of the tube was 600°C. and the particles were screened between 60 and 90 mesh I.M.M. screens. The values in the tables are the average of many observations.

These experiments require elaboration, but suggest that the swelling of coal, when the particles are in a plastic condition, is a progressive process. Rough experiments suggest that under the conditions described here the formation of cenospheres begins when a particle has fallen a distance of about 2 inches in a tube maintained at 600°C.

In all the experiments quoted no evidence can be advanced as to the actual temperature the particles attain, or the exact time they are in the tube. The difficulties encountered in attempting to supply this information are so great that no accurate data are yet available. It will be recognized that the laws governing the fall of particles cannot be applied to the particles of coal entering the tube. The coal particles fall for some 7 inches and then enter the heated tube when

they become small solid spheres, and may then increase in volume up to 11 to 40 times the size of the coal particles and yield cenospheres. A number of measurements have been made of the time required for the particles to fall through the heated tube, and the values have been found to vary from 1.2 to 4 seconds.

The experiments described above have been repeated on a larger scale in a cast-iron retort, 20 feet high, 7 inches by 2 feet 2 inches at the top, and 1 foot 3 inches by 2 feet 9 inches at the bottom, the temperature of the retort being 600°C. The coal was ground in an ordinary pulverizing plant attached to a unit pulverized fuel plant, and

FIG. 6. COMPOSITE CENOSPHERE. MAGNIFICATION ×45

about 90 per cent would pass through a screen of 100 I.M.M. mesh. The powdered coal was introduced into the top of the cast-iron retort by means of a distributor at the rate of about 100 pounds per hour, and practically the whole of it was converted into cenospheres. The cenospheres produced were frequently agglomerated into accumulations which collected as porous masses, while a proportion were single units, but considerably larger than the remainder. These were found to consist of a number of complete cenospheres bound closely together with the appearance of being contained in a complete envelope. Single cenospheres can be detected inside the larger unit (Fig. 6). It is not possible to state whether the agglomeration oc-

curred before or after the cenospheres were formed, although the evidence points to the latter explanation. Similar results were obtained when using a retort from a setting of Glover-West vertical retorts maintained at a temperature of 900°C., again with practically complete conversion of the particles into cenospheres.

When the carbonization in the small tube was carried out under diminished pressure only 5 per cent of the particles were converted into cenospheres. The remainder were obtained as solid spheres having the same volume as the original coal particles. It must be

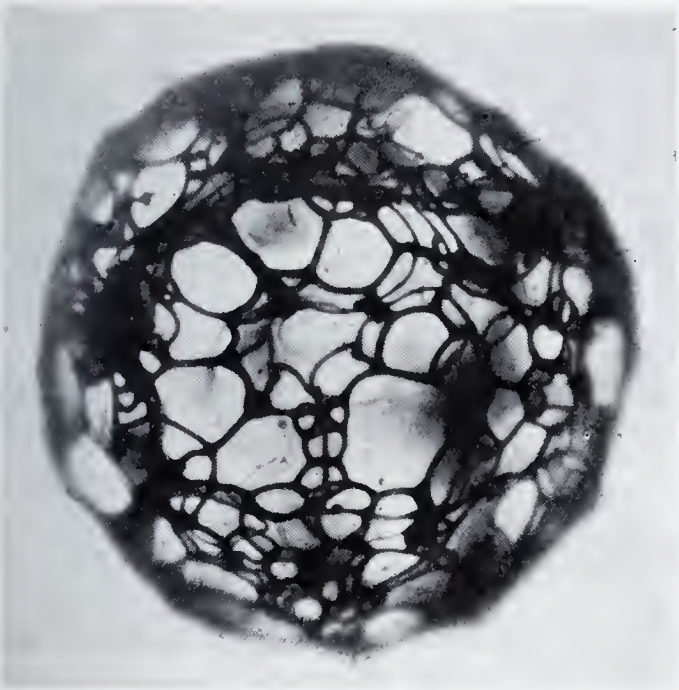

FIG. 7. PARTICLES OF PITCH CARBONIZED AT 700°C. MAGNIFICATION ×120

concluded from these experiments that in the formation of cenospheres the particles of coal actually form a sphere which is in plastic or molten condition, and this is blown out to produce a cenosphere, unless the gas is removed from the inside by some means, such as evacuation, in which case practically a solid bead or sphere is formed. This conclusion is supported by the results of experiments carried out upon particles of pitch. Typical specimens of pitch, prepared from both high and low temperature tars, and containing in certain cases only 2.5 per cent of free carbon and less than 0.1 per cent of ash, were

treated in a similar manner to the particles of coal. By adjusting the temperature of the tube, and cooling the lower end, it was possible to convert the irregular particles of pitch, obtained by grinding the lump material, into minute solid spheres. When the temperature of the tube was raised, however, to above 550°C., the particles of pitch were converted into cenospheres identical in all the major characteristics with those produced from caking coal (Fig. 7). In fact particles of pitch of softening point 80°C. behaved in a similar manner to particles of caking coal.

Fig. 8. Untreated Particles Shown at *A*. Particles of Briquetted Coal Carbonized at 650°C. Magnification ×45

The blending of coals is of such importance that experiments were carried out to ascertain the influence of mixing non-caking material with the caking coal upon the structure of cenospheres. It was necessary to adopt definite and somewhat artificial experimental conditions, and any deviation from them had an influence upon the results. The caking coal, ground to pass a sieve of 120 mesh I.M.M., was mixed in increasing proportions with powdered electrode carbon of the same degree of fineness. The mixtures were then compressed into small briquettes 1 inch in diameter and $\frac{3}{8}$ inch in thickness. A pressure of

10 tons on the square inch was used; no binding medium was required to yield a compact briquette. The briquetted material was then crushed, screened and collected between 60 and 90 mesh I.M.M. sieves. The particles were then treated in an identical manner to that adopted for the particles of coal, a temperature of 650°C. being maintained in the carbonization tube. In the case of the particles made from the coal itself, about two-thirds of the carbonized particles were only slightly larger in volume than the original particles. About one-third had been converted into cenospheres which were larger than cenospheres produced from single particles of coal (see Fig. 8, untreated particles shown at *A*). The window and lattice structures, however, were very close, the lattice being comparatively thin and the windows small and very numerous. The cenospheres had small protuberances over the whole of the surface and resembled in a general way the appearance of a blackberry. Each individual particle present in the larger particle appeared to have retained its individuality on carbonization, and had coalesced to form a single cenosphere.

Examined by reflected light, the particles which had not been converted into cenospheres were also observed to possess the "blackberry" appearance. The tertiary structure could be detected in both types of particles described above.

In the case of the particles composed of 75 per cent of coal and 25 per cent of non-caking material, about 25 per cent were converted into cenospheres of the same size as cenospheres from single particles of coal. The "blackberry" structure was very pronounced, but little evidence of the presence of non-caking material could be detected in the cenospheres.

When particles containing 50 per cent of coal and 50 per cent of non-caking material were carbonized the majority of the particles were swollen, and the cenospheres were about one-half the diameter of those obtained with coal alone. The "blackberry" appearance was pronounced and the tertiary structure could be detected. Particles of the non-caking material, surrounded by a matrix of lustrous carbonized coal, could be recognized in the wall of the cenosphere, but it was impossible to detect any signs of flowing of material from the coal portion over the non-coking material (Fig. 9).

Particles which contained a mixture of 25 per cent of coal and 75 per cent of non-coking material did not yield cenospheres, i.e., there was no evidence of the lattice and window structure, and the carbonized particles were practically the same size as the original particles, although altered in appearance.

The author has concentrated on the structure and method of formation of cenospheres, with a view to attempting at a later stage to correlate the observations with the structure of lump coke. It would appear possible that at least three structures may be identified in lump coke, (*a*) the ordinary large bubble structure, (*b*) the secondary, window and lattice structure (cenospheres) or foam, (*c*) the minute forms which have been detected in the windows (tertiary structure).

An interesting paper by D. J. W. Kreulen, "A Laboratory Study of the Formation and Structure of Coke" (*Fuel*, 1927, 6, 171), contains

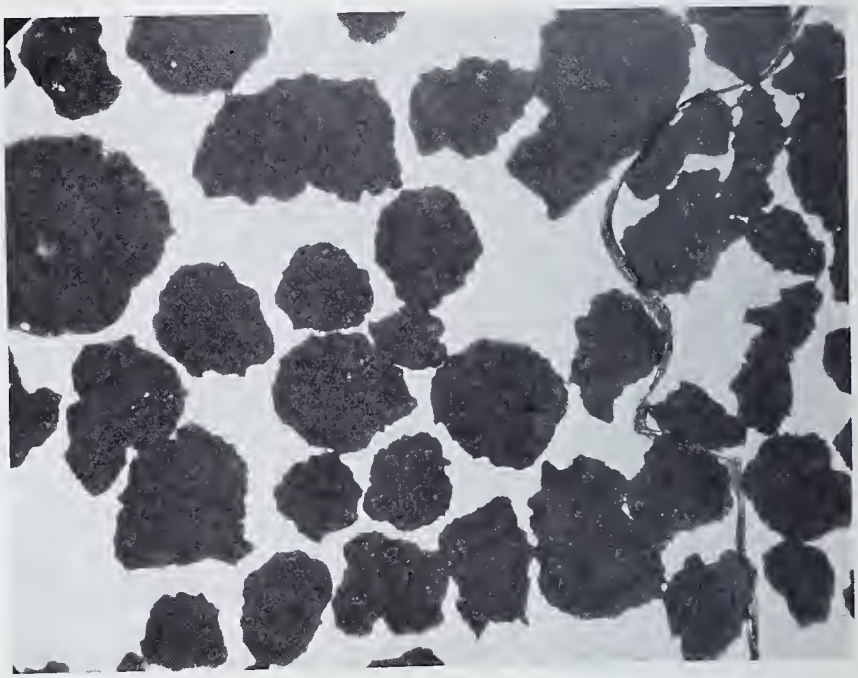

FIG. 9. UNTREATED PARTICLES AT *A*. PARTICLES OF A BLEND OF COKING COAL AND INERT MATTER. CARBONIZED AT 650°C. MAGNIFICATION ×45

a study of the microstructure of coke. Kreulen attempts to prove that the structures he has observed in lump coke are similar to those present in cenospheres. He states that the photomicrographs, of which eight are given in his paper on this aspect of his study, indicate an accordance in structure with that found in cenospheres. The subject is obviously one of great complexity, and the author does not propose to discuss it in any detail until the experiments in progress have reached a more advanced stage.

No positive information has been obtained to indicate the presence

of cenospheric structure in ordinary coke, and in order to eliminate some of the unknown factors experiments have been carried out on the carbonization of sugar.

When a mass of sugar was carbonized at 500° one portion of the coked mass was found to have a structure shown in Figure 10. This resembles the structure of cenospheres, but is obviously a foam effect. It would, therefore, seem possible for cenospheric or foam structures to be present in coke, especially where the coal has been carbonized under conditions in which free expansion is possible.

FIG. 10. FOAM STRUCTURE IN COKE PREPARED FROM CANE SUGAR. MAGNIFICATION ×45

It may be of interest to consider the effect of exposing particles of coal and cenospheres to heated air.

It was found that when cenospheres made at temperatures of 600°, 650°, or 700° from one coal seam were allowed to fall into air heated to 600° none of the cenospheres inflamed, whilst at 650°, 30 to 40 per cent ignited. It was observed that many of the cenospheres had undergone partial combustion, and in such cases the films or windows had partially or completely disappeared.

Where the windows had burned the lattices were thin and distorted.

The material of the cenospheres used in the experiments still possessed slight caking properties, and the edges of the lattice had fused and become rounded by the heat evolved during the combustion of the windows. When the windows remain intact the lattices resemble those of the original cenospheres.

The fact that many of the particles pass through the heated tube and that the windows may be removed, suggests that oxidation has occurred without the particles having attained a temperature sufficient to inflame them or to cause the combustion to proceed from the window to the lattice. Up to the present the chemical properties of the films and the lattices have not been separately investigated, and until this information is available it cannot be stated whether the two parts of the cenospheres would behave in a characteristic manner during combustion It is clear, however, that the combustion of a particle of a caking coal may proceed in stages:

(*a*). When the particle enters a zone at a sufficiently high temperature, it is converted into a cenosphere.

(*b*). The cenosphere consists of two main visible structures, windows, and lattices, and the films undergo oxidation, leaving a partly-consumed cenosphere consisting largely of lattices.

(*c*). The lattices may then burn leaving the ash of the coal.

The mechanism of combustion of a particular particle will depend to a great extent upon the temperature to which the coal particles are subjected. At temperatures just above that of cenosphere formation, the sequence (*a*), (*b*), and (*c*) probably occurs, especially in a deficiency of air, but at high temperatures combustion may be so rapid that the particles burn without the formation of cenospheres being possible.

In the case of pulverized coal, it is a general practice to admit an excess of air, but if owing to the design of the system local deficiencies of air occur, cenospheres may be produced. The cenospheres may be formed at a high temperature, and consist of coke of low combustibility, and may consequently be difficult to burn, and may escape from the system. If any considerable deficiency of air is employed large numbers of cenospheres may be produced. The author has not had an opportunity of examining this last statement, and it is given on the authority of three technologists of wide experience, with whom the subject has been discussed. The low specific gravity of cenospheres (say 0.1 to 0.5) prevents rapid settling, and thus may not be a source of annoyance close to the place of formation where the

concentration is greatest, but may become a nuisance at a distance. The author examined the dust deposited from a cement works at a point about $\frac{3}{4}$ mile distant, and found that some 4000 particles were deposited per square foot in 8 hours, of which a large proportion were cenospheres completely or partially consumed (Fig. 11).

The solid products evolved from other typical industrial furnaces have been collected and examined. Cenospheres have been identified in the dust from the following: (1) a locomotive (dust collected through the window of a railway carriage), (2) a Channel steamer

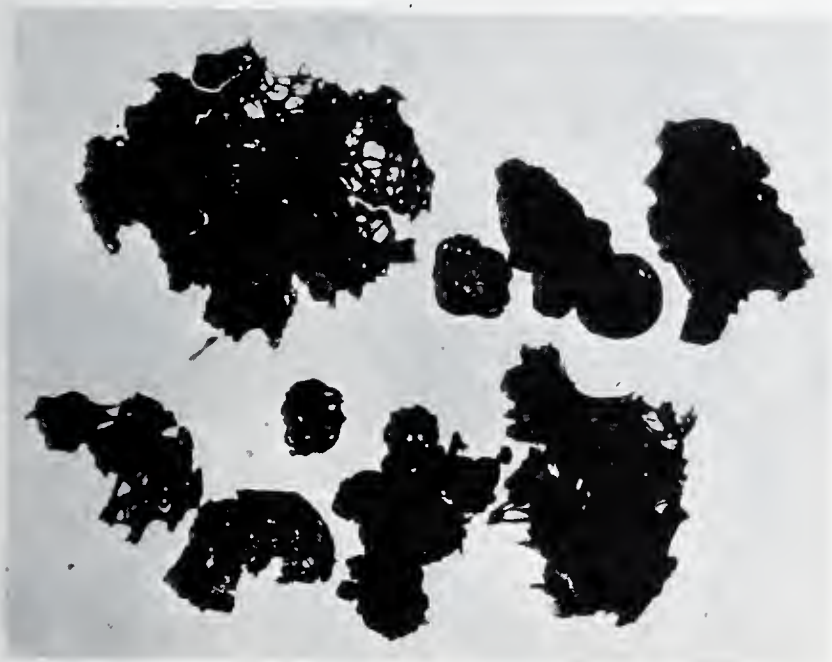

FIG. 11. DUST CONTAINING CENOSPHERES FROM CEMENT WORKS. MAGNIFICATION ×45

(dust collected 50 feet from funnel), and (3) an ordinary steam-raising plant (collected at a distance).

Other practical aspects of the subject cannot be ignored. For example, in any process devised to obtain producer-gas or water-gas from powdered coal the temperature to which certain types of coal-dusts are raised before they come into contact with the air or steam may have an important influence upon the behavior of the particles. The dusts from non-caking coals do not produce cenospheres, and in the combustion of pulverized coal or in coal-dust explosions differ-

ent results may be expected than when these bodies are produced from caking-coal particles.

The carbonization of coal in the form of a suspension in gas has become of considerable technical interest in view of the "McEwen-Runge" method of low-temperature carbonization. The process embraces three stages of the treatment of coal in the form of fine particles, the heating of the particles being effected by means of hot gases. The first stage is the modification of the caking properties of the coal; the second, the low-temperature carbonization of the

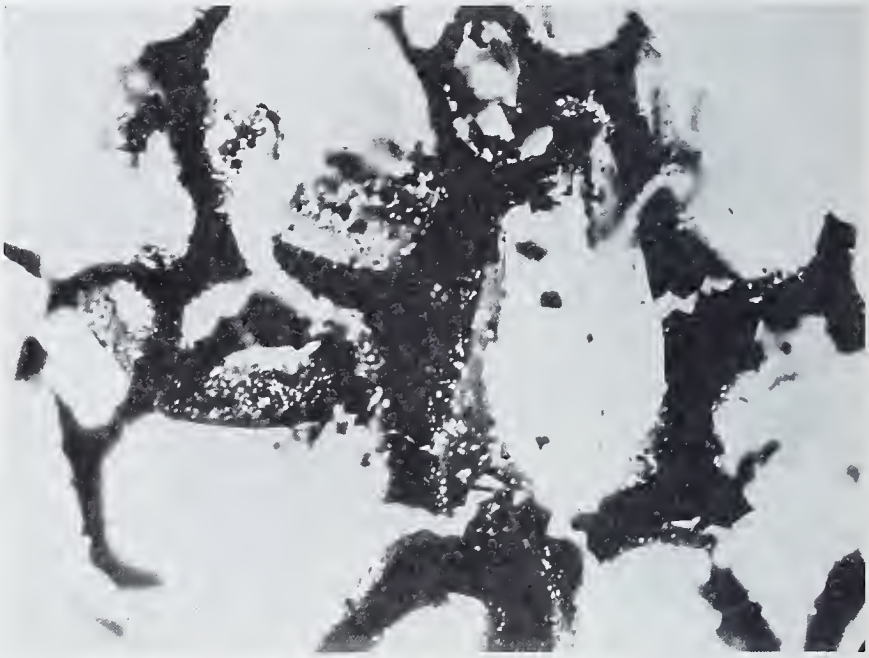

FIG. 12. CENOSPHERES TREATED WITH CARBON DIOXIDE AT 950°C. MAGNIFICATION ×250

above product; and the third, the combustion of the carbonized product in powdered form in furnaces for steam-raising.

An investigation is proceeding at the Fuel Research Station upon the reactivity and combustibility of coke. A method has been perfected which consists of passing 100 ml. of carbon dioxide over the specimen of coke in twenty minutes under carefully controlled conditions, and measuring the carbon monoxide formed. Cenospheres prepared at 800°C. were treated with carbon dioxide at 950°C. in the prescribed apparatus, and when they had been exposed to the treat-

ment for three hours it was observed that many of the windows had disappeared completely, but in some cases whole windows or large areas remained, which on close examination were found to be pierced by minute circular perforations (Fig. 12; compare this figure with Fig. 5).

In the case of one coal, and under the conditions previously mentioned, the perforations in the windows measured 0.005 mm. in diameter. The greater number of perforations can be detected in the windows, but others can be seen in the lattice, concentrated, it would appear, on the edge of the windows. This observation, which is being examined more closely, suggests that portions of the cenospheres are more reactive towards carbon dioxide, and, in fact, that active areas are present on the surface. The result is of secondary interest as indicating a similarity in the character of the windows and lattice, and as supporting the observation that the windows may be removed first during the combustion of a cenosphere.

NEW ASPECTS OF COAL ECONOMY

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1. Coal as a Direct Fuel

Some decades ago, coal was a fuel which was principally burnt in grates. Not only was the idea of obtaining by-products entirely excluded, but even the caloric effect was usually very poor. We have only to remember the primitive stoves for domestic use, and the great fuel consumption required for the production of steam, which 40 years ago gave a useful effect of scarcely 10 per cent.

With regard to the first-mentioned point, domestic use, a number of considerable improvements have been evolved through the introduction of special hearth-stoves, and especially as a result of central heating. For the latter system we may probably expect a considerably enlarged and improved sphere of application. Indeed, the tendency of many experiments of recent years has been to show that the projects for procuring a centralized production of heating for the great groups of population, and even for whole towns, need not exist merely in the imagination, but may be carried into actual practice; so that steam (or hot water) will be distributed in the same way as gas and electricity at present. This problem (and it decidedly *is* a problem) is not a question of a method of production, but of the conservation of heat; and the caloric expert may yet find occasion to do extensive and useful work in this direction; until the time will come, when practically speaking, it will no longer be necessary for coal to enter the towns. The coal will be transformed at a central works into latent heat of water and steam and gas; after of course having previously been distilled in the most economical way, with a view to the primary recovery of by-products and gas. Here too is a mighty sphere for heat economy.

It is difficult to give the exact figures for the value lost through the uneconomical use of household fuel; but there is an example of one nation compared with another, which illustrates to a striking degree the economical importance of this problem, namely, a comparison of the consumption of domestic fuel in England and Germany respec-

tively, which we will take for a normal period before 1914. In 1913, when the population of Germany amounted to seventy million inhabitants, German households consumed about twenty million tons of coal; while during the same period, the population of England, which consisted of forty million inhabitants, consumed sixty million tons of coal for domestic use. So that for an equal population, England would have consumed 105 million tons of coal for household purposes; which would have been 5 times more than the German consumption; thus involving a heat wastage of round about 340 million dollars per annum.

The production of steam for power purposes has undergone very considerable improvements during the last three decades, and it might well be said that the useful effect has increased by 50 per cent. But that does not alter the fact that the transformation of caloric energy into motive energy, i.e., for power of various kinds, amounts at present only to a maximum of 15 per cent, and it is only in cases where both heating and power are used (in sugar factories, breweries, distilleries, and the like) that a heat yield of 70 per cent, from coal, is possible. The greatest producer of steam, the railway engine, has, however, remained in the background most of all, by reason of its nature; its yield being now still only about 7 per cent (1.2 to 1.4 kgm. (2.6 to 3 pounds) coal per horsepower hour). We shall later have occasion to show what great economical possibilities can be expected in this very domain of traction, with the help of new thermic systems.

2. Coal Distillation at Low Temperatures

The development of coal economy tends away from the treatment of coal as a chemical material. The first steps in this direction were made in the coke works and the gas industry. Although at first they were a primitive kind of coal refinement, they have added by 30 per cent to the value of coal as a raw material in by-products.

During the last two or three years, the principle of coal distillation at low temperatures has again engaged much attention. This has been with a view to the production of more oils, and more volatile oils to meet the rapidly increasing demand for liquid fuels for motor traction. Political motives have a say here too. Petroleum is geographically so unevenly distributed, that America has more than 80 per cent of the world supply, and other countries are therefore very dependent upon the few remaining petroleum-producing countries. Until a short time ago, the only possible way for countries without

petroleum to increase the availability of oil, even partially, was by recovering as much liquid hydrocarbons as possible from their own national raw material, coal.

Yet, there are two serious obstacles in the way of this system of low temperature distillation, which together with its product "coalite" has made some progress in England. These will be discussed later.

First, it can only very partially solve the oil problem. Indeed, the attainable quantity of oil distillates from pit coal is out of all proportion to the present great demand for oil, let alone the future. If we take England as an example, and assuming that, by a general cooperative endeavor, the low temperature distillation could be carried out with a quantity of 20 million tons of coal per annum, then, with a maximum yield of 80 kgm. of hydrocarbons per ton of coal, this would mean a quantity of 1,600,000 tons of hydrocarbons, of which at the outside 20 per cent (i.e., 320,000 tons) would be light oils, 40 per cent (i.e., 640,000 tons) would be middle-heavy, and 40 per cent (i.e., 640,000 tons) heavy oils. Yet England at present already imports approximately 2,000,000 tons of light oils for motor traction. So that, if low temperature distillation were possible to the extent mentioned, it would only be able to provide for one-seventh of the present demand for light oils in England, and in addition to this, the coal oil would not be equal in quality to petrol.

Secondly, low temperature distillation as a general system is impossible, in view of the fact that the chief product of the distillation, the half-coke or coalite, is unsuitable for the main application of coke, namely, the blast furnace industry. For, the chief requirement for this industry is the producing of solid, big-lump coke, which, among other things, can stand the strain of blast furnace stoking; and so long as this demand exists, the application of low temperature distillation in this domain will remain doubtful.

Therefore, for coalite production, or distillation at low temperature, there is little chance for expansion in the application of half-coke as household fuel in open fires. But we have already seen how uneconomical this English system of providing domestic fuel is. This system costs England 40 million tons of coal per annum more than should be necessary for household purposes, seen from the caloric point of view; so that viewed from the national economic standpoint, it must be considered a bad system to base the distillation of pit coal in general upon the production of half-coke for open grates. At the same time it must be admitted, that so long as the uneconomical

system is persisted in, it is far better to distill the coal required for this purpose according to the low temperature system, than to burn the coal in open fires. We take no notice here of the hygienic side of the problem, namely, of the soot formation caused by the direct combustion of coal in such large quantities in open fires. If only from this last consideration, the practice of making coalite deserves recommendation, so long as the practice of open fires has not been abandoned in favor of the much more economical system of central heating with the help of water or steam, preferably centralized for great areas.

3. The Ammonia Problem

About ten years ago, when the Chili saltpeter to a large extent supplied the needs of agriculture in the way of nitrogen, and when the synthetic preparation of ammonia from the atmosphere did not yet exist as a great industry, the recovery of ammonia in coal distillation was a very important problem, and in the course of time the yield of ammonia in cokeries and gas factories was increased from 8 to 12 kgm. of salt per ton of coal. But the fact must not be lost sight of, that the average coal could give a yield of from 50 to 70 kgm. of ammonia salt per ton of coal. With the Mond process, by total gasification at low temperatures, 80 per cent of this theoretical possibility has already been attained. It is mainly owing to the meager heat value of the chief product, gas, that this process can find no general application.

Even if after the introduction of the synthetic preparation of ammonia from the atmosphere, the recovery of ammonia in coal distillation has to a great extent lost its vital importance, yet the problem of ammonia still remains a very important economic question. The application for agricultural purposes of fixed nitrogen may still be carried on to a much greater extent, provided it is prepared cheaply; and an abundant use of this main fertilizer would, by reason of the essential intensification of the cultivation of the soil, be a benefaction to humanity, through the provision of foodstuffs.

That these matters are of intense interest to the coal industry, will be evident from the following figures. If, with the approximate 200 million tons of coal at present distilled in the world, the theoretically possible yield of ammonia salt could only be raised to 40 kgm. per ton of coal, this would mean a production of 8 million tons of ammonia salt of 20 per cent; which is about four times more fixed nitrogen than at present is used in the form of Chili saltpeter.

Now, the present method of coking in the coke-furnace and gas industry shows no prospect of this possibility being reached; but at present a new method of coal transformation has been found, which, among other things, renders possible a considerable further recovery of ammonia from coal, simultaneously with its distillation without the expensive appliances which are required for the synthetic preparation of ammonia from the atmosphere, and without extra preparation of hydrogen.

Such a system of coal transformation is as a matter of fact the fruit of the studies pursued under the author's guidance, at the Private Technological Institute at Dongen, in Holland. According to this process, which will later on be more fully discussed in connection with motor fuel, the coal is transformed in the course of gasification, to pure molecular active carbon; the system being called by the author the "Carbonalphanization" of coal. When this system will have made more headway, larger and larger quantities of coal will be completely gasified according to the formula: $CO_2 + C = CO$; and this at such low temperatures that the recovery of nitrogen as ammonia in quantities of 40 to 50 kgm. of salt per ton of coal will become possible.

The formation of ammonia is fixed by two conditions; i.e., that both the nitrogen and the hydrogen meet in a nascent condition. This is the case in the production of the motor fuel Carbonalphine, whereby also a limited quantity of steam is dissociated from the glowing coal at temperatures varying between 100° and 850°C. maximum. So that here we have the same conditions as in the "Mond" process with this favorable difference, however:

a. That the quantity of steam remains very limited.

b. That the recovery (of the other distillates too) becomes much simpler, as in the Carbonalpha system much less steam and gas per ton of coal are formed.

c. That the abundant carbonic acid present binds the ammonia formed to ammonium carbonate, which on account of its low tension, allows of its being occluded as such, e.g., in the Carbonalpha itself; which product would then bring in a new form of nitrogen fertilizer, in a much enhanced and richer form. The nitrogen contents of this product would increase, with the result that the disadvantageous sulphur would be replaced by active carbon, which could be a valuable and permanent means of helping to enrich the soil. The cost price of the final product (ammonium carbonate

occluded in active carbon) permits of this occlusion being resorted to, for it is higher than the cost price of Carbonalpha. Thus the problem of obtaining ammonia from coal, continues to be of paramount importance for every country and every nation, although its vital significance has diminished.

4. Solid Coke by Low Temperature Distillation

The principle of low temperature distillation need not necessarily stand in the way of the production of solid, big-lump coke, that is to say, industrial coke. Tests in this direction have been going on for several years at the Private Technological Institute at Dongen, in Holland under the supervision of the author. With the system which we have called continuous and intermittent distillation of pit coal, the coal is internally and externally subjected to increasing temperatures rising from 15° to 1,100°C. in a continuous system of coal, going downwards, and every particle of volatile and liquid distillates leaves the furnace, without having been subjected to higher temperatures than those in which they originated. The coal oil is obtained in abundance and is of light modifications. As the final temperature of the distillates is 1,100°C., solid and big-lump coke is always obtained.

According to this idea, coal is continuously introduced from above, the cooled coke being taken out at the bottom, after the water gas formed has served as a vehicle for the evasive distillates in the form of steam and gas.

Further studies by the Institute mentioned have led to a modification of this system. There were two objections to this, namely, that one was still bound to special (baking) coal, and that the tension of the permanent gases obtained was not sufficient for suspending the liquid distillates in the form of steam in any considerable quantity, not even at the low temperature which exists in the furnace at the top.

These considerations have led the afore-mentioned institute to alter the mechanism of the system, while retaining its essentials, viz., continuous and intermittent distillation; by introducing the cold coal from below, and conducting the glowing coke from the top of the furnace. Thereby outward heating could also be carried out more rationally, viz., going downwards, and by means of a special (non-mechanical) arrangement, it has become possible to obtain the coke in briquetted form. For this reason the coking system has also been called "Cubus Coke Distillation."

By this system it will be possible to work up fine coals of the most

diverse composition into good, hard coke in cube form, together with the recovery of all distillates of more precious composition than those which at present occur in the usual low temperature distillation.

We must here restrict ourselves to these general indications.

Considerable economies could be effected in the realm of coal distillation in the directions indicated. Indeed, the existing distillation in coke furnaces and in the gas industry still affords an opportunity for considerable economizing in the direction indicated, and that both financially and calorically. The disadvantages of the present coke and gas furnaces are as follows:

a. They require too much for their own heating, viz., 500,000 calories for coke furnaces, and 800,000 to 900,000 calories for gas furnaces, per ton of coal distilled. These figures could be reduced to 250,000 to 300,000 calories if the continuous and intermittent distillation system were applied, in which it is likewise possible to recover usefully the exothermic heat, which amounts for most coking coal to about 250,000 calories, thereby saving on an average 300,000 to 500,000 calories for other purposes.

b. They work sharply dissociated, and the original oils themselves are not recovered from the coal, but their component parts are, for example, the so-little-employable tar. The oil yield is therefore not only qualitatively, but also quantitatively insufficient, viz., only 35 to 40 kgm. of tar per ton of coal in the case of coke furnaces, and 40 to 45 kgm. in the case of gas-furnaces; while the low temperature distillation produces from the same coal 80 kgm. or more of light oils.

c. The dissociation which occurs in old furnaces still further decomposes the hydrocarbons to the final product hydrogen, which, however, is of little caloric value in gas form, while the purpose of the intermittent distillation is this: not to dissociate, but to keep as much carbon as possible bound in *liquid form* to as little hydrogen as possible. That is to say, by making the most of the limited hydrogen contents, by recovering this not in a free state, but bound to carbon in a liquid or gaseous state.

d. The yield of ammonia is also spoilt by continual dissociation, for in all existing furnaces, temperatures rule which are in excess of the dissociation temperature of 700°C. of the once-formed ammonia, while in the case of intermittent distillation they remain low.

This improvement, which is so easy to bring about, by means of continuous and intermittent distillation, is well worth paying atten-

tion to. Thus we get a higher yield of coal oil of better quality, and of ammonia, without sacrificing the quality of the main product, coke.

5. Motor Coal Versus Steam Coal

The greatest use of pit coal takes place, without a doubt, in the production of steam on water and on land; and with regard to the latter, principally for traction purposes with the locomotive. It will approach the truth fairly closely if we fix the amount of coal used for the production of steam, especially for shipping and railway traction, including the steam electrical central stations, at 500 million tons per annum. The principal economies of the future will be possible; the transformation of latent coal heat in transportation by means of steam is still accomplished with considerable calorie loss, in spite of the many technical improvements which have been brought about in this direction. The best boilers have now reached a thermic yield of over 80 per cent and the most modern steam engines give a horsepower with $4\frac{1}{2}$ kgm. of superheated steam of 700 calories. This signifies a yield of:

$$635 : 4\tfrac{1}{2} \times 700 \times 0.8 = 16 \text{ per cent}$$

However, railway traction, the greatest consumer of steam coal, works with a considerably lower yield. It consumes 1.2 to 1.4 kgm. of coal per horsepower hour, of which the dynamic equivalent is 635 calories; that is to say, only a yield of barely 7 per cent.

Good modern motors have at present a yield of 40 per cent, but their application to railway traction is at the moment still excluded, because, so far, combustion engines can only work with petrol, or oils of which the calorie expenditures are at least two or three times higher than those of coal. In addition to which, the availability of the oils is insufficient to provide for the needs of railway and shipping traction. This is especially the case with countries which have to import these oils principally from abroad.

The reason why internal combustion engines, although they have three to four times the efficiency of steam engines, have up to the present day not been used generally by the different traction systems, is that it has not been practicable to provide internal combustion engines with fuel using coal as raw material. Coal is abundantly present in the countries which actually make use of internal combustion traction. There has, however, been a question as to whether suitable fuel could be produced at prices much below those of oil.

Many efforts have been made of recent years to effect industrial development in this direction. An example of this is the liquefication of pit coal by the methods employing high temperature and high pressure, by means of hydrogenation. The fact must not be overlooked, however, that such systems of production impose conditions that considerably increase the cost price. There are two main difficulties: first, the necessity of producing considerable quantities of hydrogen; and second, having to work them up for the purpose of the hydrogenation of coal under very high pressures (150 to 200 atmospheres). These are serious objections in themselves, even if it is not assumed that they render the liquefaction system financially impossible in comparison with the present cost price of oil in the countries which must import the oils. The production of hydrogen for the needs of the liquefication of coal in such large quantities as would be necessary for shipping and railway traction, would require gigantic technical installations. Coal contains a maximum of 5 per cent of hydrogen; that is to say, 50 kgm. per ton. To liquefy a ton of such coal to the hydrogen equivalent of light oils (petrol) would require the production of 80 to 100 kgm. of hydrogen. This means about 1,200 cubic meters, which must be compressed to a minimum of 150 atmospheres. To do this in sufficient quantities to supply anything like the requirements of water and railway transportation, an industry would have to be created which would excell any other industry in size, extent, and financial investment.

The second objection to the movement in favor of the liquefication of coal is a matter of principle, so we shall put it in the form of a question. It is this: Is the motor fuel which contains the most hydrogen, viz., petrol, the most ideal fuel in itself? And, in consequence, is the hydrogenation of coal really necessary to manufacture an ideal motor fuel from coal?

We consider it here necessary to state our reasons for believing that the light oils, on account of their high hydrogen contents, are undesirable. We take petrol as an example, because every effort is being made to produce this synthetically on a large scale for future traction purposes.

Petrol contains 15 per cent of its weight in hydrogen; we must, however, remember that this 15 per cent represents more than 50 per cent of the caloric value of petrol. The hydrogen has not a very low combustion point (550°C. for half combustion, and 600°C. for complete combustion in an oxygen atmosphere); but it possesses an

enormous combustion speed (fulminating gas has a forty times greater combustion speed than carbonic gas, for example). For this reason, a very sudden combustion occurs in the engine immediately after ignition, which usually occurs 25° before the dead compression point. Combustion at this position of the crankshaft (335° to 25°) can produce no efficient energy. On the contrary, it results in the unpleasant knocking of the engine, which is such a nuisance, that for large land engines no higher hydrogen content than 10 per cent can be allowed; and for fast-running automobiles, drastic measures have had to be employed in order to prevent the knocking of the engine ("anti-knock" measures). For this reason people have not even hesitated to recommend the deadly poisonous tetra-lead.

But apart from the disadvantages of abnormal combustion speed, hydrogen has still the property of burning on contraction, whereby temperatures of from 1,500° to 1,800°C. arise, which are exceptionally unfavorable for the remaining oils in the motor cylinder, the latter being cracked up to still heavier hydrocarbons in a very unfavorable way. This cracking brings with it the further great disadvantage, that the heavy hydrocarbons which thus arise demand still greater quantities of oxygen for complete combustion; and also a continually rising combustion temperature, according to the degree in which the oxygen has become corrupted by the cracking. These two conditions, more oxygen and higher temperature, do not exist when the piston is descending in the engine; hence, insufficient combustion. This is also the reason why, notwithstanding the hydrogen content, or, to put it better, because of the hydrogen content, petrol does not as a rule burn very satisfactorily in motors (a Diesel motor gives 1 h.p. with 1,700 cal. and a petrol motor requires for 1 h.p. 3,000 cal.).

With respect to both production and application, there are two serious objections to petrol which is so rich in hydrogen. And yet there is so much hurry to imitate petrol by the hydrogenation of coal and heavy oils, a mighty endeavor being made in all quarters. It might be surprising, that with the desire and the necessity for the discovery of a new artificial motor fuel, sight has been lost of the disadvantages of petrol. After the recognition of these disadvantages, one could have asked oneself whether it was not more desirable to look actually for some other fuel than the imitation petrol; yet from all sides, especially in Europe, and also in America, researches are being made, and commissions of inquiry are being established, both

by states and by private individuals, to achieve the imitation of benzine by synthesis. The idea has taken a strong hold on the public imagination that without petrol, or another fuel with a high hydrogen content, no motors, or at least fast-running motors, could be possibly kept going.

To tell the truth, the petrol motor has indeed worked wonders of recent years, especially in automobile traction, and has reached a state of perfection which from the technical point of view may well be admired; but we must not be deceived by this apparently perfected instrument. We must not forget that this ideal motor is practically nothing more nor less than the child of the fuel, petrol, and that, both its continuation and its operation will become quite changed, as soon as it is fed with some other kind of fuel.

The question now arises: If petrol is *not* the ideal fuel for motors, what then *is?* The answer is, that fuel which contains a medium of combustion having a much lower ignition temperature for combustion than hydrogen; provided that the medium does not suffer from the great disadvantage of hydrogen, namely, the enormous rate of combustion. And in addition to this, that medium must be incorporated intimately with the fuel, and in a quantity which would at least be equal in weight to that of the hydrogen in petrol. It would further be desirable if this new fuel could be obtained and applied, in liquid, plastic, or solid states. Such a new fuel would have to be available by being formed from any procurable coal or coal complex, in a cheap and simple manner, on the spot; that is to say, a national motor fuel for every country that possesses coal.

It has required the study of many years on the part of the Private Technological Institute at Dongen, in Holland, under the guidance of the author, to arrive at the realization of this aim. The solution has now been accomplished by means of a process, originating in this quarter called the "Carbonalphanization of coal," regarding which we wish to make some statements here.

Carbonalpha is the name given by us to the product, *pure elementary carbon of the alpha-modification*, obtained by the decomposition of CO according to the formula $2\,CO = C + CO_2$, at low temperature.

According to the general view, this reaction was in itself so slow, that a simple industrialization without more ado was out of the question. We have now succeeded, however, after research work of many years, in hastening up this reaction to such an extent by autocatalysis following a preliminary suitable inoculation of the reac-

tion, that application on a large scale became industrially possible, and that by very simple means, and at normal pressure.

By this process—for the sake of simplicity, we speak for the time being of coke—carbonic oxide was made from rough coal, by the reduction of carbonic acid over glowing coal at 850 to 900 degrees according to the formula:

(1) $$CO_2 + C \text{ (coke 900)} = 2\ CO\ (-38.600)$$

CO being thereupon split up into carbonic acid and carbon according to the formula:

(2) $$2\ CO = C\ (C - x\ 450°C + CO_2\ (+38.600)$$

So that the working of the process consists of a repetition of the reversion of the two reactions, whereby the carbonic acid remains continuously in circuit. Small losses of CO_2 are covered by adding a small quantity of limestone to the coal (coke) charge. The first reaction being reversed for the sake of the second, it is also possible to recover the exothermic heat of the second. The second reaction takes place further after inoculation with a strange catalyzer, quite auto-catalistically; i.e., the fresh carbon obtained serves as catalyzer for the new reaction now starting, which is thereby continually renewed and promoted, so that with suitable apparatus and at suitable speed, it takes place with great activity. Under these conditions, and should there be sufficient concentration of the auto-catalyzer, the process runs on apparently to 100 per cent, while a small amount of carbonic oxide, that may not have reacted, enters the new circuit.

The Carbonalpha system is thus essentially a process of complete gasification of the fuel to carbon monoxide gas, and dissociation of this gas to alpha-carbon and carbonic acid.

As—with the exception of the inoculation of the reaction—no strange materials take part in the reaction, the product obtained is very pure, and consists only of elementary amorphous carbon of alpha-modification, which is the most active carbon.

Now this carbon—christened "Carbonalpha"—has precious qualities hitherto unknown, both from a chemical and from a physical point of view; viz., it is:

(*a*) Molecularly formed, and therefore of the finest imaginable structure;

(*b*) It has very great affinity to oxygen, and therefore

(*c*) It has a very low combustion point (200°C., i.e., about 400°C. lower even than hydrogen);
(*d*) It has great capillarity; and hence
(*e*) Great absorption power, or occlusion-power; it can thus absorb considerable quantities of vapors, as for example hydrocarbon vapors (coal oils);
(*f*) Its specific absorption power is small, the occluded matter therefore becomes free again on a very slight raising of temperature; finally it has
(*g*) A very great lubrication power.

The qualities (*b*), (*c*), (*d*), and (*e*) are characterized by the collective work "Activity," of which (*b*) and (*c*) indicate the chemical, and (*d*) and (*e*) the physical.

All these properties, without exception, make just this modification specially suitable for motor fuel, in which it is a principle of weight, that the stuff should consist exclusively of the element C, molecularly obtained, thus quite of simplex form in that which concerns the conditions of combustion; in the presence of a sufficient quantity of oxygen the combustion must be perfect. An intermittent combustion accompanied by the separation of materials with a higher combustion point, as is the case, for example, with petrol, is in this case out of the question. The only possible product of combustion is CO_2, without any intermediate combustion, in the presence of sufficient oxygen. Of further importance for the purpose in view is the great capillary occludation power, accompanied by the comparatively small specific absorption power, by which, for example, occluded gases are driven out early by increase of temperature.

It is of importance, that the occluded gases or fumes lost their vaporific tension by reason of the occlusion, and are thus present as liquids. This is of great significance for the caloric value of the fuel; e.g., 1 kgm. of hydrogen takes up the space of 14.43 cubic meters as gas (at 0°C. and 760 mm.; air = 1), and has a caloric value of 34.400 calories which if occluded in the a-carbon, are taken up and closed in as liquid.

This occluding power of the a-carbon with regard to gases and vapors thus signifies a very great accumulation of calories in the alpha-C; so that the latter also serves as a very strong heat-accumulator.

In this active-carbon, the oil fumes of the foregoing intermittent distillation can then be occluded. The product is then a very pre-

cious motor fuel, which we have named "Carbonalphine." This material can be used in liquid, plastic, or solid form. One can mix the Carbonalpha either with heavy oils or with ash-free carbon of the most various volatility, if a sufficient quantity of this active carbon is intensively incorporated in the complex of the fuel, in order to fulfill the function of preliminary combustion which the hydrogen fulfills in the case of petrol. This is done now in a much milder and better fashion. A content of 20 to 30 per cent will be sufficient, regardless of the function of the motor. For a fast-running motor, a higher content of the amelioration-medium will be desirable; while a slower-running motor can do with a lower percentage.

It is clear that with this fuel, in which elementary active carbon of very low combustion point (200°C.) and mild combustion, has taken over the rôle of the hydrogen which forms fulminating gas (of petrol), a much more ideal, more natural, and more useful combustion takes place.

Now, what is the function of this fuel—Carbonalphine—whether liquid or dry—in the motor? The Carbonalpha burns at 200°C. (400° lower than hydrogen) (and very mildly) to carbonic acid. So that the compression heat in the cylinder provides in all circumstances a mild preliminary combustion of the Carbonalpha (without electric ignition) and this will bring about in the charging a temperature of over 1,200°C. immediately, and, this over the whole cylinder charge, as the a-C is incorporated intimately in the fuel. Immediately on entering the cylinder, the absorption of the absorbents will be discontinued as a result of the compression heat (500° to 700°C.) and the occluded matter (hydrogen) has become free. As, however, it was present in a condensed form (as a liquid), and now enters in the form of gas or vapor, this aggregation-change will cause considerable raising of the maximum, and also of the average pressure in the cylinder. After the first combustion of the Carbonalpha, combustion will occur of all fuel still present, which in the meantime will have reached a temperature of above 1,200°C., no matter what it is, heavy oil or coal powder, and the combustion will be perfect in the presence of sufficient air. In the case of the application of coal powder, there is no more need whatever for distilling the coal beforehand; indeed, the by-products obtained would find no more valuable use than as improved motor fuel; only the recovery of the ammonia can now still play a rôle; and should this yield cover the costs, then it may be desirable to Carbonalphanize

the coal as a whole, and to occlude the coal oils obtained in the x-C. This too—the total Carbonalphanization of the coal—will be desirable for that coal which is rich in ash, especially in mineral components. Ash-free (or poor,) and refined coal too, can be added to the Carbonalpha in the form of dust in the proportions of 2:1; or 3:1; or even 4:1.

It is clear that with such a changed fuel, the motor too may be much simplified and altered. The two-stroke form, without valves, clutches, carburetor, or fuel pump, or magnets, is now possible and suitable, as well as the fuel. The motor as well as the fuel can be perfected according to the principle that both fuel and motor form one common means for transforming the latent energy of heat into that of motion. A motor was designed by the engineers of aforementioned Institute for Technology, in accordance with this idea, with a bore of 110 mm. and a stroke of 130 mm., which, at 1,200 revolutions per minute would bring a yield per cylinder of 33 I.h.p., with a consumption of 1,600 to 1,700 calories per horsepower. This Institute, which has been mentioned several times already, hopes to have this motor running within three months, Carbonalphine being used, both liquid and dry.

The distillation problem is thus to be solved very economically by each country by the means here indicated. For the principle of the "Carbonalphanization of coal" indicates coal as the source of motor fuel, this being cheaper to dig, and geographically more favorably located and distributed than petroleum. So that by this system practically every country can produce its own fuel for motors, from its own national raw materials. In connection with the simplicity of the process, both the costs of production and those of the laying out of factories are small. Therefore, economically, the "Carbonalphanization of coal" means, that the thermically better yield of motors, which up to the present could only be utilized for the expensive calories from oil, can in future also be utilized for the cheap calories from coal. So that the motor can now also penetrate into the tremendously extensive domain which is at present occupied by steam power, and which absorbs the greater half of the world's coal comsumption, the much greater part being for railway and shipping use. This economy would be considerable, the calorie consumption of the locomotive being at present approximately 10,000 units per horsepower hour with motor traction, (this would become 1,600 to 1,700 units per horsepower hour, or an economy of

6:1); for shipping and other applications of energy by steam, as 3:1. This advantage of coal need not lead to the oil situation being placed at a disadvantage. The "Carbonalphanization" of heavy oils, which are at present inferior to petrol, will give a usefulness to those oils which are more difficult to sell, and thus a value equivalent to that of petrol. This conservation of fuel thus applies not only to coal, but also to oils.

6. Résumé and Conclusions

The foregoing gives some impression of the aspect of the prevailing coal crisis. Some directions were indicated, in which the known methods of the application of coal can develop into important economies. In addition, less well known, or quite new methods, of working up coal were indicated, which in the near future can lead to still greater economies and improvements.

In conclusion, we summarize these different possibilities:

A. In the way of household fuel, considerable economies may still be effected, especially in regions geographically between 40 and 60 of northern latitude, which contain a civilized population of nearly 400 million people and whose consumption of fuel can be estimated at $\frac{1}{3}$ ton of coal per annum per inhabitant, or, roundly at 133 million tons per annum.

This amount can without difficulty be distilled beforehand for the future, with recovery of the by-products. Caloric economies can also be effected, by the still further development of central heating, both for domestic and public purposes. The caloric efficiency of the cokes obtained need not be lower than that of the original pit coal. And this means an economy of about 25 per cent of the above quantity of coal, i.e., 33 million tons, which would then be obtained in the form of a like quantity of by-product in ameliorated form (gas and coal oil), of which the value can be put at roughly $1.50 per ton of coal worked up, or roundly $200,000,000.

Improvement of combustion—technical development of continuous and intermittent distillation methods for the production of suitable household coke and at the same time recovery of precious by-products, thus deserve the continued attention of scientists and practical men.

B. With the existing *coal distillation* for *cokeries and gas industry* there is the possibility of increasing the recovery from coal oils by 30 per cent, the highest quality of cokes being maintained. This

increase can never solve the oil problem completely, not even in its present extent. Supposing that under pressure of scientific development, and with government support, the quantity of coal at present subject to distillation, 250 million tons per annum, were rationally distilled with a yield of 80 kgm. of oils per ton of coal. this would mean for the whole world still only 20 million tons of coal oils, or only about 12.5 per cent of the present earth oil consumption. This modest advance, however, signifies economically an average increased value of coal which may be calculated at $1.50 per ton of coal worked up, or $375,000,000.

An organized endeavor to distil intermittently as much as possible deserves strong recommendation, *provided the highest requirements of the quality of the coke are not lost sight of.*

C. The fuel economy attainable in the *blast furnace* industry, likewise lies in the domain of intermittent distillation, and at the same time in that of the process of reduction and smelting itself. By letting the reduction and the smelting occur separately, the one with gas, the other with solid carbon, as indicated above, a thermic economy of 40 per cent is possible.

With an annual world production of 80 million tons of iron and steel, this economy in theory meets an application of 120 million tons of coal, and thus amounts in round figures to 45–50 million tons of coal per annum.

Although in connection with the duration and expensiveness of the blast furnace installations, this economy can be effected only very gradually, the amelioration here indicated still deserves the attention of all who do research work in the field of blast furnaces.

D. With regard to the question of *ammonia,* the new method of transforming coal, which we have called the Carbonalphanization of coal, provides favorable conditions with respect to the increased recovery of ammonia. So that the latter can be increased to 40 to 50 kgm. of salt per ton of distilled coal, as compared with 8 to 12 kgm. with the present distillation.

Supposing that the complete gasification for the aforementioned purposes of traction should extend during a human lifetime to 300 million tons of coal, then this would mean a production of 12 million tons of ammonia salt of 20 per cent, i.e., a few times the present consumption of nitrogen for the whole world, or of about 300 million dollars at half the present money value. So that in the future the nitrogen can be applied liberally and at small cost as an artificial fertilizer, for the provision of food.

As the production of nitrogen direct from coal is the most natural and simple means of production, the new method of coal transformation represents for these otherwise identical reasons also a great financial and general advantage. The production of steam is still consuming the greater part of the world's coal production, and the greater part of that perhaps more than 500 million tons per annum is used for steam traction on railways and ships. Consequently, in this field the greatest economy of coal would be obtained by means of the internal combustion motor. There are two ways in which coal may be made serviceable to motors: in the first place in the process of liquefying, which is fairly complicated, because it necessitates high pressures and an intentional hydrogen production, by which means a fuel is obtained, at a rate of production approaching that of natural oil. This fuel also has the essential drawbacks of benzine as a motor fuel, because of the hydrogen in it. In the second place we have the process of "Carbonalphanizing," that by the simple means of complete gasifying, converts coal into pure, active carbon, igniting at a low temperature and being a better motor fuel (Carbonalphine, as well by occluding heavy oils) from the distilling process of earth oils or coal in Carbonalpha, as by mixing powdered coal free of ashes with Carbonalpha, so that the latter functions as a medium of combustion and predominates in the motor fuel, like the hydrogen in benzine.

A field of application lying open here, equal to half the world-consumption of coal, a possibility of coal economy is given that exceeds all other means and that will bring about an important improvement in economical, financial and social spheres, so that these new processes of coal transformation deserve thorough attention of all the coal and oil world.

DISCUSSION

F. C. Greene (Old Ben Coal Corporation, Chicago, Ill.): I did not have the pleasure of hearing the first two papers, as I was at one of the other sessions during that time, but I am particularly interested in this paper that Dr. Kithil has just presented for Dr. Aarts.

It seems to me that I have never run across anything that intrigues me to the point that this production of pure carbon substance has. Perhaps I am all wrong on it, but it does seem to me that if that can be made a commercial process, it is going to settle a great many of our problems in the coal industry in this country.

I had written to Dr. Kithil and asked him for further information as to this process and I expected to get it here, but either because I am too dense or

because I came in too late, I did not get it. So I would appreciate your sketching on the board, if it is permissible, how Dr. Aarts makes this stuff.

KARL L. KITHIL: I have some notes here which have not been published because a paper finally can get so long that it would require a week to study over all the notes, but to give you just the information you ask for: 2CO equals C plus CO_2, but to make it possible you must reverse, which occurs by changing the temperature as a reverse action during the system, into just CO_2 plus C equals 2CO.

That is actually the whole reaction of the whole process, which actually gives you what I have seen, pure molecular carbon, and nothing else.

Carbon from natural gas, carbon black they call it, and the oil blacks which are used in many industries, in the microscope are shown to be $\frac{1}{40,000}$ mm. in diameter, whereas this product is $\frac{1}{400,000}$ part of a millimeter in the microscope, which is a very unusual thing. It is neither solid nor liquid nor anything else; it is just a molecule.

Each individual particle is combustious. In other words you do not need a match to light it, and as I said, we know very little about the motor that is coming out, but it is under way, and it is a Diesel type two cycle motor. They are now actually making large motors and in two or three months we should have the full results.

MR. GREENE: These reactions are classic. You take the C plus O_2 equals CO_2, plus 174,500 B.t.u., and so on, but what I want to get at is how he makes that stuff.

MR. KITHIL: I am sorry that I did not receive the pictures in time to show them to you, because otherwise I could give you much more information, and it is very difficult to explain it to you without them. I have some sketches here.

MR. GREENE: But he has worked out mechanisms for carrying out the idea?

MR. KITHIL: There are very few mechanisms. It is a smaller plant—

MR. GREENE: And they have worked them out to a point where they show profits?

MR. KITHIL: In Holland they have experimental plants which have been examined by American engineers. In Belgium, outside of the city of Brussels, there is in existence today a larger plant. I have not heard how they are operating today, but New York engineers who were over there say that it is the most wonderful plant. That is the best I can say, because the plant has been built since I was last over there.

MR. GREENE: The thing is so fundamental that I think this paper, if it could have been accompanied by an apparatus or something of that kind,

would have created quite a great sensation in this conference. I am quite sincere in that.

MR. KITHIL: It is a very important thing. The simplicity is so important. For instance, you ask about the mechanism. The biggest mechanical apparatus is perhaps the Cottrell separator, with 60,000 volts.

MR. GREENE: I was wondering how he precipitated ash from the raw, the water gas, for that is practically what he starts with.

MR. KITHIL: Ash residue never bothers it a bit. Leave it there. It is automatically carried out.

MR. GREENE: It is very interesting and I hope to learn more about it.

CHAIRMAN DAVIS: Is there any further comment on this paper?

I have some notes that I made here of questions I wanted to ask the other speakers, but they have left. Perhaps some one in the audience would like to discuss them.

One is in regard to Mr. Vandergrift's paper. He mentions the use of carbon and heating plates in his flues. I have heard that carborundum is subject to expansion when used for such purposes. It is sort of a blocking effect you might say. I wonder if anybody has had experience on that?

Then has anyone seen the test plant in which these tests are carried out? I would like to know something of the capacity of that.

I notice he mentions the quality of cannel coke, but does not go into details. It seems to me that it is pretty hard to produce a firm coke from cannel coal, and I did not get just the means taken to cause the coal to flow through the retort. I do not know whether he used a plunger or just depended on the incline of the retort or of the flow I should think that some of the coking coals, without mechanical means, would stick in the retort.

Then there are a few comments on the paper presented by Dr. Evans that I noted down. Some years ago we were interested in carbonizing pulverized coal in a small laboratory experimental way, and we noticed that we got an abnormally large yield of gas. Of course, we heated rapidly I judge Dr Sinnatt in his work has heated quite rapidly. The tar was pretty much cracked up, and I wonder if that is pretty generally true.

Now in speaking of these windows, I do not see how you get a transluscent film of coal. I do not know whether I am correct in assuming that they are transluscent or not.

We are very much interested now in the swelling properties of coals in our work at the Bureau, and I was wondering if the swelling properties of the various constituents vary. I took it from the paper that they found that a vitrain had more pronounced swelling properties than others of the banded constituents. I do not know whether that is true or not. We have not investigated that particular field and would like to have information on the subject

Those are all the comments I have noted. If there is any further discussion or comment, I would like to have it.

C. D. ULMER (Koppers Company, Pittsburgh, Pa.): I should like to ask the last speaker whether any United States patents have as yet been granted on this process.

MR. KITHIL: Sixty per cent of the patents have been issued in Holland, England, Belgium and France. In the United States, they have all been applied for, but I believe that so far none have been issued. They have been held up for various reasons. You know best how long it takes to issue, but they are all applied for.

CHAIRMAN DAVIS: I would like to ask the last speaker if the dry product which he mentioned for use in internal combustion engines is anything like the Trent process amalgam. That is a mixture of finely pulverized coal and oil from which the ash has been eliminated.

MR. KITHIL: It is similar where you use a straight Diesel engine, but the Aarts idea is to get a different type of engine, where you can use the mixture of tar oils which you otherwise cannot use anyway. Mix these with these products, then through what they call the carbon-alpha action, get another portion of 50 or 60 per cent of what we here call gasoline out of that particular material. They also want to apply that in oil plants later on. Very little has been done along that line though.

But otherwise it is not similar because they can use otherwise the dry carbon-alpha which naturally they would not use for the motor. You might call it semi-dry, a slimy mass. The dry is used for rubber tires, of course, and other industries.

MR. GREENE: Have you seen this material?

MR. KITHIL: Oh yes, surely. There is some at the custom house. I would have brought it, but it has not been received by me.

MR. GREENE: Does it resemble soot that has been inside the chimney for a long time? I do not mean fresh tarry soot.

MR. KITHIL: Yes, absolutely. The fact is that the discovery of Dr. Aarts' is the catalyzing value of carbon-alpha. Its being molecular carbon, he used to think he had to put a lot of iron in there in some form, because that is known in all catalyzers, of course, but here he cut it out and he came out with that reaction. It is catalyzed. It has all the fumes and solution.

CHAIRMAN DAVIS: It is a case of auto-catalysis.

MR. KITHIL: That is exactly what it is, and that has been proved in a lot of cases where they have studied the thing.

J. E. Noeggerath (Dr. Ing., Berlin, Germany): Is it not possible to use the alpha coal without tar in the motors? I should think it would be better because you would not have the mechanical difficulty with the pistons. The only difficulty would be with solid residues. So I think you could continue to use the alpha coal alone.

Mr. Kithil: Either alone or if you want to use up ash free or other finely ground coals.

Dr. Noeggerath: But I should think that it is free from ashes. Where you cannot get any other coal sufficiently free from ashes, and there would be any difficulty with the ignition, you might do the way I do with the gasoline engines in which I burn crude oil just by adding a little hydrogen and oxygen. I use a small dynamo from the motor and that generates a sufficient amount.

Mr. Kithil: The idea was, of course, to make use of products which otherwise could not be used and add them to the carbon-alpha, and to do away with the things for which there is no market.

It is just like the oil industry. With certain tars, by means of the same reactions, together with coal products, they are able to get a good deal of gasoline out of certain heavy tars which they cannot use today, but, of course, not much is known about that but can be known because it is all experimental.

Dr. Noeggerath: I want to say there must be a big future in the coal Diesel engines.

GENERAL CONSIDERATIONS ON THE ORIGIN AND NATURE OF BITUMINOUS COALS

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Coals which on being distilled at a low temperature give a high yield of tar and gas with a great heating value, or which give by extraction with organic solvents a considerable yield of bitumen are generally designated as bituminous coals. From that point of view it is necessary to consider as bituminous coals not only many stone- and brown-coals, but also boghead coals, which yield a very high percentage of tar.

A detailed examination of bogheads, however, forces one to conclude that all bituminous coals must be divided in two classes: (1) humic coals, which give a great yield of bitumen by extraction with organic solvents and a low temperature tar very rich in phenols; (2) boghead coals, which give a very small quantity of bitumen extracted with organic solvents and a very great yield of low temperature tar almost free from phenols; the best specimens of the latter coals are free from humic substances.

Between these two classes there are coals of intermediate character, and the transition from the first class to the second is imperceptible. These coals of intermediate character are generally found in nature.

On the origin of the bitumens of humic coals we have at the present time the following theory based on well-known facts. These bitumens are formed from vegetable waxes, fats and resins, organic conpounds which during geological periods have lost their oxygen. By the separation of carbon dioxide from acids and water from alcohols, they are changed into hydrocarbons, that is, into bitumens, which represent "native substances composed of hydrocarbons substantially free from oxygenated bodies, largely soluble in carbon disulphide"[1]

In fact the young brown coals give by extraction with organic solvents a mixture of waxes, acids, hydrocarbons and resins. With increase of the geological age of coals, the quantity of waxes in them gets smaller and the quantity of hydrocarbons greater, so that in

[1] Abraham, "Asphalts and Allied Substances," p. 21.

typical stone-coals we find a great quantity of hydrocarbons, as was shown by Pictet and Fischer.

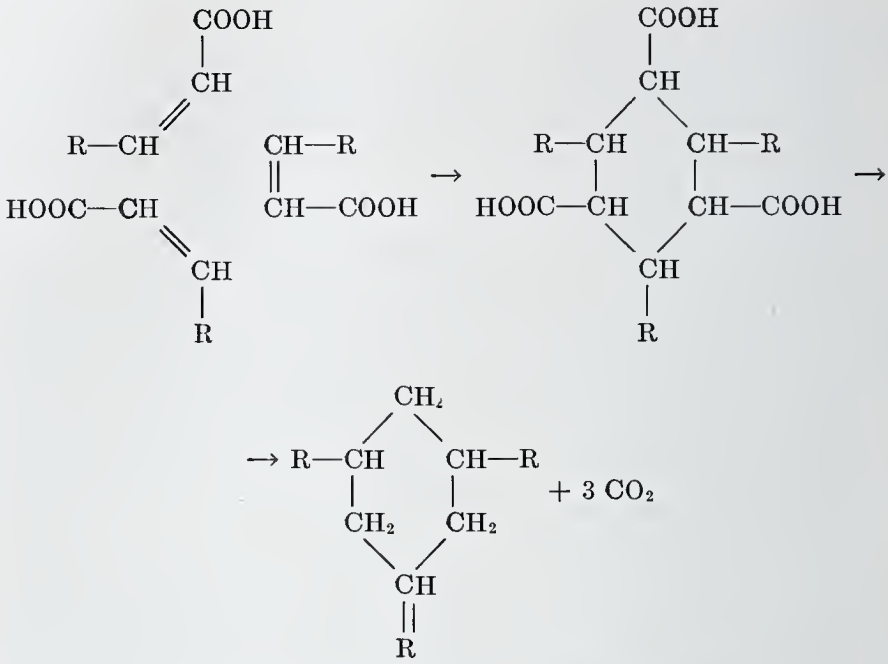
We must not forget, that we know only the initial (waxes) and the final stage of bituminization, but we do not know, in what manner saturated acids of the aliphatic series were changed into the cyclic hydrocarbons that were found in coals by Pictet; it is naturally very difficult to explain how these hydrocarbons were formed. Also nothing is known up to the present time about the process, which brought about the transformation of fats of algae into bogheads, which are not soluble in organic solvents and hence do not contain notable quantities of free organic acids and hydrocarbons, but give an important yield of low temperature tar; in this case, therefore, the process of bituminization does not take place, and the acids of fats of algae undergo transformation in another way.

About the transformation of organic acids of the fatty series in nature we have only the hypothesis of Engler, who supposes that they are changed during geological periods into a mixture of hydrocarbons (oil). To the present time this hypothesis could not find sufficient confirmation by investigations of bituminous bodies. From a theoretical point of view, however, we must object to this hypothesis, that the acids of the fatty series can be decomposed with separation of carbon dioxide or carbon monoxide only in the following manner:

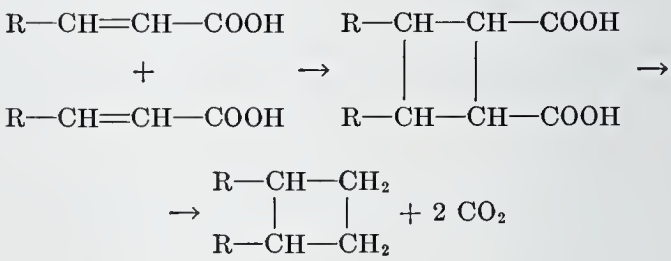
$$\text{I (a)}\quad R - CH_2 - CH_2 - COOH = R - CH_2 - CH_3 + CO_2$$
$$\text{(b)}\quad R - CH_2 - CH_2 - COOH = R - CH = CH_2 + CO + H_2O$$
$$\text{II}\quad R - CH = CH - COOH = R - CH = CH_2 + CO_2$$

By all these transformations organic acids of the fatty series can give only saturated and unsaturated hydrocarbons with an opened chain of carbon atoms. Among the oils we find, however, not only mixtures of saturated hydrocarbons with open chains of carbon atoms, but more frequently mixtures of cyclic and aliphatic saturated hydrocarbons. So the composition of oils is in some contradiction with the theory of Engler. To avoid this contradiction Engler supposed, that unsaturated hydrocarbons formed from acids undergo polymerization and give by this process a mixture of cyclic hydrocarbons having a saturated character. It is possible, however, to give another explanation for the formation of cyclic hydrocarbons; unsaturated acids of the fatty series undergo polymerization and give cyclic carboxylic acids, which further transform on separating carbon dioxide into cyclic hydrocarbons, as follows:

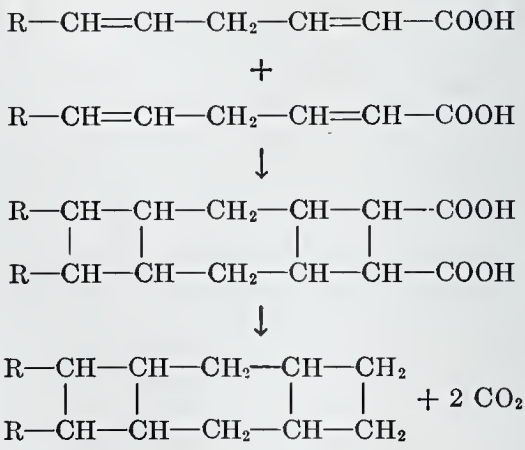
I



II



III



etc.

From the theoretical point of view, such a process is naturally possible, but it has never been proved that these processes have taken place anywhere in nature. It is known, from the investigations of Gregory and Wetherill, that the fatty acids are the most stable compounds, which remain unchanged after the decay of animal bodies and the hydrolysis of fats. We had recently a confirmation of the conclusions of these investigators. After the last earthquake in Crimea there appeared white masses on the surface of the Black Sea near the shores of Crimea. These white masses consisted, as was found by Kharkewich, of a mixture of fatty acids, calcium salts of these acids and probably of anhydrides of fatty acids; no traces of glycerides were found in these white masses. We must suppose that these acids were formed from sheep-tallow, which had formed the cargo of a ship that had been sunk or wrecked on the Black Sea. At the same time on the surface of the Black Sea was found a yellow mass, which was shown to be unchanged beeswax; this wax had been part of the same cargo. This confirms that waxes are more stable compounds than fats.

We have, however, at the present time no basis for conclusions on the transformations of fatty acids during geological periods. It is necessary to know more definite facts about the transformation of fatty acids both for an explanation of the origin of cyclic hydrocarbons, which are part of the constituents of bituminous coals, and for the construction of a theory on the origin of cyclic oils (oils with asphaltic basis). The answer to these questions should be found by the investigation of boghead coals, which, according to the investigations of Zalessky, R. Thiessen and others represent the product of the transformation of fats of algae. The transformation, however, does not pass through the stage of aliphatic saturated and unsaturated hydrocarbons and of common bitumen, soluble in organic solvents, because bogheads are almost insoluble in these solvents. All bogheads that have been investigated are characterized by a great percentage of hydrogen in comparison with all other coals, and by a great percentage of oxygen in comparison with oils. Further, bogheads give a great yield of low temperature tar, although they contain a very small percentage (about 2 per cent) of substances extracted with organic solvents. In the Table I are given analytical results concerning the organic matter of bogheads; the yield of tar in this table is that obtained from crude bogheads. Low temperature tar obtained from these bogheads contains a very small percentage

of phenols (not more than 2 per cent); this fact can be considered as a basis for the conclusion that bogheads do not contain humic substances.

TABLE I

COUNTRY	BOGHEADS	PERCENTAGE OF				YIELD OF LOW TEMPERATURE TAR
		C	H	O	N	
Czechoslovakia	Unterreichenauer Agneskohle (Falkenau)	77.21	8.05	14.30	0.44	—
	Braun-u. Glanzkohlengewerkschacht (Zieditz)	77.04	7.44	13.73	0.83	36.40
	Falkenau-Egerer Bergbaugesellschaft	72.06	6.78	13.77	0.89	32.1
Russia	Pobedensky (Moscow) I	75.19	9.88	8.12	1.23	45.5
	Pobedensky (Moscow) II	73.63	8.06	11.67	0.84	31.6
Siberia	Khakhareisky.					
	Compact slab	76.50	9.80	11.87	0.83	42.6
	Lamellated boghead excavation No. 1	78.50	10.73	8.74	1.24	42.0
	Lamellated boghead excavation No. 6	66.64	9.84	—	—	25.0
	Bituminous shale (Slab of Nasledoff)	63.36	9.71	—	—	12.0
	Kasjanowsky boghead (gagat) Cheremkhowo	81.10	8.34	8.68	1.12	39.1
	Matagansky	78.69	10.41	7.29	0.56	48.8
	Sukhokujatsky	76.82	8.55	12.78	0.79	—

TABLE II

FRACTIONS OF TAR FROM CHEREMKHOWSKY BOGHEAD VOLATILE WITH STEAM*

BOILING POINT OF THE FRACTIONS AT 760 MM.	SPECIFIC GRAVITY AT 15°	IODINE NUMBER	C	H	S	O
90–140°	0.737	125.3	85.05	14.30	0.38	—
140–190°	0.734	101.5	85.18	13.72	0.53	0.57
190–240°	0.808	78.9	85.16	13.34	0.43	1.07
240–280°	0.838	70.9	85.09	12.85	0.59	1.47

* All fractions were free from organic bases and phenols.

All the fractions of low temperature tar obtained from boghead contain a great quantity of oxygenated bodies, as can be seen from

TABLE III

HIGH BOILING FRACTIONS OF TAR FROM CHEREMKHOWSKY BOGHEAD*

BOILING POINT AT 15 MM.	SPECIFIC GRAVITY AT 15°	IODINE NUMBER	S	C	H	O	HYDROXYL NUMBER	SAPONIFICATION NUMBER
100–150°	0.839	70.7	0.56	84.92	12.63	1.83	7.7	3.7
150–190°	0.865	66.7	0.55	84.99	12.47	1.99	11.8	4.25

* The fractions were free from organic bases and phenols.

TABLE IV

FRACTIONS OF TAR FROM KHAKHAREISKY BOGHEAD VOLATILE WITH STEAM

BOILING POINT AT 760 MM.	SPECIFIC GRAVITY AT 23°	TODINE NUMBER	C	H	S	O
80–100°	0.713	146	83.3	12.40	0.78	3.52
100–125°	0.729	139	83.2	12.30	0.65	3.85
125–150°	0.751	128	83.06	12.22	0.61	4.11
150–175°	0.770	113	82.72	12.07	0.65	4.56
175–200°	0.786	98	82.42	10.93	0.67	5.98

TABLE V

HIGH BOILING FRACTIONS OF TAR FROM KHAKHAREISKY BOGHEAD

BOILING POINT AT 15 MM.	SPECIFIC GRAVITY AT 23°	IODINE NUMBER	C	H
150–175°	0.869	97.3	83.76	12.22
175–200°	0.885	94.4	84.23	11.83
200–225°	0.905	91.6	83.99	11.37
225–250°	0.928	91.6	84.46	11.11

TABLE VI

THREE FRACTIONS OF TARPARAFFIN FROM KHAKHAREISKY BOGHEAD

MELTING POINT	ACIDIC NUMBER	SAPONIFICATION NUMBER	HYDROXYL NUMBER	IODINE NUMBER	C	H	O
62–66°	0.0	5.3	0.0	7.2	84.1	14.2	1.7
52–55°	0.0	8.5	0.0	12.8	84.3	14.3	1.4
43–48°	0.0	14.7	0.0	16.6	84.0	14.3	1.7

Tables II to X. These oxygenated organic compounds could be formed only by decomposition of oxygenated bodies present in

TABLE VII

LIQUID OILS SEPARATED FROM TARPARAFFIN FROM KHAKHAREISKY BOGHEAD

BOILING POINT AT 16 MM.	ACIDIC NUMBER	SAPONIFICATION NUMBER	HYDROXYL NUMBER	IODINE NUMBER	C	H	S	O
185–220°	1.8	26.3	7.2	45.10	85.2	14.0	0.40	0.40
220–280°	1.4	32.9	18.5	40.2	85.0	13.6	0.43	0.97

TABLE VIII

FRACTIONS OF TAR FROM MATAGANSKY BOGHEAD VOLATILE WITH STEAM

BOILING POINT AT 760 MM.	C	H	S	O
60–200°	82.4	12.9	2.2	2.5
200–250°	83.1	12.9	2.0	2.0
250–265°	83.3	12.3	2.5	1.9

TABLE IX

HIGH BOILING FRACTIONS OF TAR FROM MATAGANSKY BOGHEAD

BOILING POINT AT 20 MM.	SPECIFIC GRAVITY AT 15°	IODINE NUMBER	C	H	S	O
100–175°	0.857	80.7	83.28	12.34	2.17	2.21
175–230°	0.878	70.4	84.01	12.15	2.47	1.37
230–280°	0.915	65.3	82.50	11.51	2.89	3.10

TABLE X

TARPARAFFIN FROM MATAGANSKY BOGHEAD

BOILING POINT AT 5 MM.	ACIDITY NUMBER	SAPONIFICATION NUMBER	HYDROXYL NUMBER	IODINE NUMBER	C	H	S	O
205–240°	5.88	13.82	3.54	47.3	85.54	11.86	1.97	0.66
240–275°	3.40	7.13	8.38	49.3	84.06	11.40	2.21	2.33

bogheads, probably by decomposition of organic acids and their anhydrides.

All the unsaturated hydrocarbons and oxygenated compounds of tars from Cheremkhowsky, Khakhareisky and Matagansky bog-

heads belong to the aliphatic series, as they give by oxidation with potassium permanganate, almost exclusively monobasic acids of the aliphatic series; non oxidized saturated compounds belong also to the aliphatic series.

The fractions of tars boiling at high temperature, as can be seen from the Tables III, VI, VII and X, contain small quantities of acids and a considerable percentage of saponifiable compounds (probably anhydrides). These acids and saponifiable compounds could not be formed by the low temperature distillation of bogheads, so that it is necessary to suppose that these compounds exist in bogheads. However as organic solvents did not extract these compounds from bogheads, we must admit, that they exist in bogheads not in a free state, but in a state of polymerization and anhydrization.

The facts observed during the investigation of boghead tars allow us to make such conclusions. Bogheads contain products resulting from a high degree of polymerization and anhydrization of fatty acids. On heating at 360° to 400° the organic matter of bogheads is depolymerized and forms by this process acids and anhydrides of acids, which are not stable under such conditions and decompose on forming saturated and unsaturated hydrocarbons, ketones and possibly other oxygenated compounds. A small quantity of acids and anhydrides formed by the process of depolymerization distills over with gases and vapors of volatile products without decomposition and forms constituents of the low temperature tar.

If that conclusion is true: first, we can find such conditions of treatment of bogheads with chemical agents, that allow processes of depolymerization to take place and free organic acids to be formed; second, it is possible to find among bogheads specimens in which processes of polymerization did not go as far as in bogheads investigated up to the present time and which contain free acids; third, by hydrogenation of bogheads under the conditions of the Bergius, process, products of polymerization of unsaturated acids with a cyclic structure must separate carbon dioxide and form complex cyclic saturated hydrocarbons.

These three conclusions were experimentally confirmed by the further investigation of bogheads.

The destruction of bogheads was carried on by boiling them with an ethylalcoholic solution of sodium hydroxide and subsequently with an iso-amylalcoholic solution of sodium hydroxide. Before the treatment with alkaline solutions, the bogheads were finely

ground and extracted in a Soxslet-apparatus with benzol and chloroform. The results of the investigation of acids obtained by treating bogheads with alkaline solutions and of their esters can be seen in the Tables XI to XVIII.

From these results we must conclude, that the investigated bogheads, consist in fact of polymerized and anhydrized acids; among these acids there are also hydroxyacids, which give saponified lactones. Among all these acids, however, we did not find acids of waxes with 25 to 30 carbon atoms in the molecule. This fact is not astonishing since microplants, such as algae, contain only liquid fats.

TABLE XI

EXTRACTION OF SUKHOKUJATSKY BOGHEAD WITH AN ALCOHOLIC SOLUTION OF CAUSTIC SODA; ETHYLESTERS OF ACIDS

	ESTIMATED	ESTIMATED		CALCULATED FOR $C_9H_{18}O_2$	ESTIMATED	CALCULATED FOR $C_{12}H_{24}O_2$	ESTIMATED		CALCULATED FOR $C_{18}H_{36}O_2$
		I	II				I	II	
Boiling point	Up to 120°	120–160°	—	—	160–200°	—	200–230°		
Pressure in mm	760	15	—	—	15	—	15	—	—
Yield in grains	0.2	0.6	—	—	0.4	—	0.5	—	—
C	66.2	68.12	68.28	68.3	71.6	72.0	75.54	75.46	76.05
H	10.97	10.04	10.25	11.3	11.24	12.0	10.92	11.07	12.69
Acid number	—	24.5	—	—	30.3	—	72.8	—	—
Saponification number	—	296	—	—	268	—	199	—	—
Molecular weight	—	189	—	158	208	200	280	—	284

The second conclusion, made after the investigation of boghead tars, is confirmed by the fact that some bogheads of Siberia (the lamellated Khakhareisky boghead) include 10 per cent of acids and of their anhydrides which were extracted with organic solvents.

The confirmation of the third conclusion was found by the hydrogenation of Sukhokujatsky boghead under the conditions of the Bergius process. The results of the investigation of hydrocarbons obtained by hydrogenation of the boghead can be seen in the Table XIX. These results permit of the conclusion, that the hydrocarbons must belong to the cyclic compounds of the composition C_nH_{2n-2}. As it is quite possible to disrupt by hydrogenation the cyclic com-

pounds with the formation of hydrocarbons with open chains of carbon atoms, whereas the formation by this process of cyclic hy-

TABLE XII

EXTRACTION OF SUKHOKUJATSKY BOGHEAD WITH AN AMYLALCOHOLIC SOLUTION OF CAUSTIC SODA; METHYLESTERS OF ACIDS

	ESTIMATED	ESTIMATED		CALCULATED FOR $C_9H_{18}O_2$	ESTIMATED	CALCULATED FOR $C_{11}H_{22}O_2$	ESTIMATED		CALCULATED FOR $C_{18}H_{36}O_2$
		I	II				I	II	
Boiling point	Up to 120°	100–140°	—	—	140–175°	—	175–245°	—	—
Pressure in mm	760	20	—	—	20	—	20	—	—
Yield in grains	1.5	1.0	—	—	1.2	—	2.7	—	—
C	64.7	68.40	68.32	68.3	70.94	70.9	76.86	76.65	76.05
H	10.76	10.50	10.41	11.3	10.28	11.8	10.15	10.47	12.69
Acidic number	—	12	—	—	19.6	—	29	—	—
Saponification number	—	312	—	—	234	—	184	—	—
Molecular weight	—	179	—	158	238	186	305	—	284

TABLE XIII

EXTRACTION OF SUKHOKUJATSKY BOGHEAD WITH AN AMYLALCOHOLIC SOLUTION OF CAUSTIC SODA. ACIDS FROM SALTS WASHED WITH ETHER

	ESTIMATED		CALCULATED FOR $C_5H_{10}O_2$	ESTIMATED	ESTIMATED		CALCULATED FOR $C_6H_{12}O_2$	ESTIMATED
	I	II			I	II		
Boiling point	100–132°	—	—	132–162°	162–187°	—	—	187–215°
Pressure in mm	760	—	—	760	760	—	—	760
Yield in grains	0.8	—	—	1.2	1.2	—	—	1.0
C	57.23	57.03	58.9	59.41	62.47	62.26	62.07	—
H	9.80	9.58	9.8	10.04	9.96	10.00	10.30	—
Acidic number	493	—	—	447	356	—	—	224
Saponification number	493	—	—	506	447	—	—	374
Molecular weight	113	—	102	110	127	—	116	150

drocarbons from aliphatic compounds is quite impossible, we must conclude that the cyclic hydrocarbons obtained by the hydrogena-

TABLE XIV

EXTRACTION OF SUKHOKUJATSKY BOGHEAD WITH AN AMYLALCOHOLIC SOLUTION OF CAUSTIC SODA; METHYLESTERS OF ACIDS FROM SALTS WASHED WITH ETHER

	ESTIMATED	CALCULATED FOR $C_9H_{18}O_2$	ESTIMATED		CALCULATED FOR $C_{10}H_{20}O_2$	ESTIMATED		CALCULATED FOR $C_{12}H_{24}O_2$	ESTIMATED	CALCULATED FOR $C_{16}H_{30}O_2$	ESTIMATED (CRYSTALLINE)	CALCULATED FOR $C_{22}H_{44}O_2$
			I	II		I	II					
Boiling point	100–140°	—	140–175°	—	—	175–215°	—	—	215–260°	—	59–60°*	—
Pressure in mm	20	—	20	—	—	30	—	—	50	—	—	—
Yield in grains	1.0	—	1.6	—	—	1.2	—	—	0.9	—	0.5	—
C	68.20	68.3	70.08	69.98	69.8	72.57	72.54	72.0	74.32	74.3	—	—
H	10.32	11.3	10.27	10.29	11.3	9.99	10.19	12.0	10.02	12.4	—	—
Iodine number	—	—	27	—	—	39	—	—	44	—	—	—
Acid number	13.5	—	21	—	—	26	—	—	46	—	26	—
Saponification number	274	—	303	—	—	271	—	—	256	—	161	—
Molecular weight	205(?)	158	185	—	172	207	—	200	218	242	347	340

* Melting point.

TABLE XV

EXTRACTION OF SUKHOKUJATSKY BOGHEAD WITH AN AMYLALCOHOLIC SOLUTION OF CAUSTIC SODA. ACIDS OBTAINED BY WASHING OF BOGHEAD WITH ETHYLALCOHOL

	ESTIMATED	ESTIMATED		CALCULATED FOR $C_4H_8O_2$	ESTIMATED		CALCULATED FOR $C_5H_{10}O_2$	CALCULATED FOR $C_6H_{12}O_2$	ESTIMATED		CALCULATED FOR $C_{11}H_{22}O_2$
		I	II		I	II			I	II	
Boiling point	Up to 120°	120–170°	—	—	170–250°	—	—	—	250–280°	—	—
Pressure in mm	760	760	—	—	760	—	—	—	760	—	—
Yield in grains	0.7	1.3	—	—	1.8	—	—	—	0.9	—	—
C	—	54.45	54.21	54.54	60.12	60.24	58.82	62.06	71.08	71.22	70.96
H	—	9.61	9.58	9.09	9.75	9.85	9.80	10.30	10.12	10.25	11.82
Acid number	—	510	—	—	409	—	—	—	147	—	—
Saponification number	—	514	—	—	467	—	—	—	288	—	—
Molecular weight	—	109	—	88	120	—	102	116	194	—	186

tion of the boghead were formed from cyclic acids constituents of the boghead by the separation of carbon dioxide, which was also found in the gas after hydrogenation.

TABLE XVI

EXTRACTION OF MATAGANSKY BOGHEAD WITH AN ETHYLALCOHOLIC SOLUTION OF CAUSTIC SODA; METHYLESTERS OF ACIDS

	ESTIMATED	CALCULATED FOR $C_{10}H_{20}O_2$	ESTIMATED	CALCULATED FOR $C_{12}H_{24}O_2$	ESTIMATED FOR THE CRYSTALLINE ESTER	CALCULATED FOR $C_{22}H_{44}O_2$
Boiling point	100–120°	—	200–250°	—	55–60°*	—
Pressure in mm	12	—	12	—	—	—
Yield in grains	1.0	—	1.0	—	0.2	—
C	69.48	69.69	72.32	72.0	—	—
H	10.41	11.62	9.80	12.0	—	—
Iodine number	16.4	—	30.5	—	—	—
Acidic number	13	—	18.5	—	13.5	—
Saponification number	277	—	220	—	172.2	—
Molecular weight	200	172	255	200	326	340

* Melting point.

TABLE XVII

EXTRACTION OF MATAGANSKY BOGHEAD WITH AN AMYLALCOHOLIC SOLUTION OF CAUSTIC SODA. ACIDS FROM SALTS SOLUBLE IN ETHER

	ESTIMATED	CALCULATED FOR $C_{11}H_{22}O_2$	ESTIMATED	CALCULATED FOR $C_{16}H_{32}O_2$	CALCULATED FOR $C_{18}H_{36}O_3$ (HYDROXY-ACID)
Boiling point	100–120°	—	120–200*	—	—
Pressure in mm	20	—	20	—	—
Yield in grains	1.3	—	0.5	—	—
C	70.43	70.89	74.83	74.91	72.0
H	10.58	11.81	10.25	12.48	12.0
Iodine number	30.4	—	—	—	—
Acidic number	110	—	76.3	—	—
Saponification number	271	—	172	—	—
Molecular weight	206	186	325	256	300

* Acids are solid at the ordinary temperature.

Such a polymerization of unsaturated aliphatic acids can naturally give complex cyclic acids with a very high molecular weight, that is

TABLE XVIII

EXTRACTION OF MATAGANSKY BOGHEAD WITH AN AMYLALCOHOLIC SOLUTION OF CAUSTIC SODA. ACIDS AND ESTERS FROM SALTS INSOLUBLE IN ETHER

	ACIDS										ESTERS					
		Calculated					Calculated					Calculated				
	Estimated	$C_4H_8O_2$	$C_5H_{10}O_2$	Estimated	Calculated for $C_6H_{12}O_2$	Estimated	$C_8H_{16}O_2$	$C_7H_{12}O_2$ (lacton)	Estimated	Estimated	Estimated	$C_{10}H_{22}O_2$	$C_{12}H_{24}O_3$ (hydroxy-acid)	Estimated	Calculated $C_{18}H_{26}O_2$	Estimated (crystalline ester)
Boiling point	160–175°	—	—	175–195°	—	195–210°	—	—	95–160°	Above 160°	100–200°	—	—	200–230°	—	57–62°*
Pressure in mm.	760	—	—	760	—	760	—	—	40	40	13	—	—	12	—	—
Yield in grains	1.1	—	—	0.75	—	0.5	—	—	0.8	0.5	2.1	—	—	1.5	—	0.2
C	56.39	54.54	58.82	60.09	62.06	65.05	66.6	65.62	65.08	66.98	68.52	69.69	66.6	71.6	72.74	—
H	9.63	9.09	9.80	9.52	10.30	9.60	11.1	9.3	9.84	9.75	9.57	11.62	11.1	9.55	12.14	—
Acidic number	511	—	—	433	—	220	—	—	228	209	24	—	—	29	—	12
Saponification number	544	—	—	481	—	357	—	—	333	298	309	326	—	254	262	149
Molecular weight	103	88	102	116	116	157	144	128	168	188	182	172	216	220	214	375
Per cent Ag in silver salt	51.7	55.4	51.6	49.4	48.4	43.8	42.9	—	40.1	—	—	—	—	—	—	—
Iodine number	—	—	—	—	—	—	—	—	—	—	13	—	—	22	—	—

* Melting point.

with colloidal properties. In fact it is possible to separate such acids with colloidal properties from bogheads. After treating with alcoholic sodium hydroxide, Sukhokujatsky boghead was boiled with diluted muriatic acid, washed with water and after drying, extracted with an alcohol-benzol mixture. In such a way we obtained a considerable quantity (about 5 per cent) of solid brown-coloured substances, which dissolve very easily in aqueous alkali and separate from that solution on acidifying with a mineral acid. This substance is therefore a mixture of acids. Part of this acid mixture is soluble in petroleumether (giving a vaseline-like yellow mass with the smell of fatty acids), part is soluble in alcohol (a solid yellow-brown mass

TABLE XIX

HIGH BOILING HYDROCARBONS OBTAINED BY HYDROGENATION OF SUKHOKUJATSKY BOGHEAD

	BOILING POINT	PRESSURE	YIELD	C	H	IODINE NUMBER
		mm.	*grains*			
First experiment	70–125°	50	0.7	86.38	13.27	—
	125–150°	50	1.4	85.28	12.80	—
	150–190°	35	1.7	87.35	12.80	12
	190–210°	35	3.0	86.80	12.80	11
	210–280°	35	2.6	85.35	12.35	—
Second experiment	100–150°	10	1.2	86.10	12.60	10
	150–200°	10	2.0	86.30	12.40	20
	200–260°	10	2.1	87.70	12.13	27

with colloidal properties), and the chief part is soluble in the mixture of alcohol and benzol (1:1). This last part of the acids is brown and has characteristic colloidal properties; it is very much like the humic acids, but is distinguished from them by its solubility in the mixture of alcohol and benzol.

We can now construct the following theory on the origin of coals based on the results given above. In cases when coals are formed from vegetable material containing lignin the latter is transformed according to the theory of Fischer and Schrader into humic substances. Waxes consisting generally of saturated aliphatic acids and alcohols of great molecular weight, are either preserved without any change according to their stability, or transformed into aliphatic hydrocarbons (paraffin). Unsaturated acid constituents of the

plants (generally the plants rich in lignin include a very small quantity of such unsaturated acids) are transformed by polymerization into cyclic acids, which could give by further transformation cyclic hydrocarbons. Resinous constituents of the plants are transformed by polymerization into dark colored even black infusible resins and asphaltenes (the great capacity of polymerization of peat resins was proved by our investigation on peat bitumen). The coals of such origin give low temperature tar with a great percentage of phenols (from 30 to 45 per cent), resins and asphaltenes; this fact is well known.

In the cases where coals were formed from residues of microplants, free from lignin and rich in fatty oils, all constituents of these microplants excepting the fatty oils disappeared through transformation into gases and substances soluble in water. In the place of sediment remained only fatty oils, which rapidly transformed into free acids; the latter, by further change in consequence of polymerization and anhydrization, gave boghead coals not containing humic substances. These coals give low temperature tar with a very small percentage of phenols (about 2 per cent), resins and asphaltenes.

These two types of coals are very rarely to be found in a pure state. More frequently we find among bituminous coals specimens of mixed origin. I shall show you an example of such coals in my second report. In these coals humic substances are formed from lignin according to the theory of Fischer and Schrader; aliphatic hydrocarbons are formed from waxes, which may remain unchanged in various specimens of coals to the present time, as is well known; resins and asphaltenes are formed from the resins of plants, containing lignin, cyclic hydrocarbon constituents of these coals are formed from the fatty oils of microplants according to my theoretical view. These coals give low temperature tar with a medium percentage of phenols (from 5 to 20 per cent), resins and asphaltenes.

In conclusion I must say that it gives me great pleasure to state, that through the investigation of bogheads from Siberia we not only arrive at a theory of the origin of bituminous coals, but that we may even supplement the theory of Engler on the origin of oils.

SUMMARY

The constituents of bituminous coals were formed as follows: (1) humic substances—from lignin according to the theory of Fischer

and Schrader, (2) aliphatic hydrocarbons—from waxes of plants, containing lignin, (3) resins and asphaltenes—from resins of the same plants, (4) cyclic hydrocarbons—from the fatty oils of microplants, as algae, through polymerization of unsaturated acids of aliphatic series.

THE NATURE AND PROPERTIES OF SIBERIAN BOGHEADS

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The investigation of the bogheads of Siberia and other bogheads was of great interest to me, as I hoped to find in its results some indications about the origin of bituminous coals and bitumens in general. Although these investigations are not yet finished, the results obtained allow one to make some interesting conclusions.

Among the bogheads of Siberia we meet with extremely compact formations colored from brown to almost black (Matagansky, Sukhokujatsky and Khakhareisky compact slab); we are unable to split these bogheads, and their compactness is so great, that they can be worked upon mechanically; they contain a low percentage of ash and give by extraction with organic solvents a small yield of bitumen.

Besides these compact bogheads we find frequently in the same layer formations, which can be very easily split into sheets or slices by the insertion of a wedge, laminated Khakhareisky boghead; these bogheads contain a high percentage of ash and give by extraction with organic solvents a comparatively great yield of bitumen. The results of the chemical investigation of bogheads of Siberia are to be seen from Table I. From these results the following conclusions can be made:

(1) The compact bogheads contain a low percentage of moisture and give a small yield of bitumen by extraction with a mixture of benzol and alcohol. The laminated bogheads contain on the contrary a greater percentage of moisture and give by extraction with the same solvents a comparatively higher yield of bitumen. From this fact it is possible to conclude, that we can meet with different grades of polymerization of unsaturated acids in the same layer of boghead coals; in the laminated boghead of Khakhareisky layer the polymerization of unsaturated acids did not go as far, as in the compact boghead of the same layer; owing to this circumstance, laminated boghead gives a comparatively greater yield of bitumen on extraction with organic solvents.

(2) Almost half of the organic matter of bogheads transforms at low temperature carbonization into tar.

TABLE I

BOGHEADS FROM SIBERIA	MOISTURE	IN DRIED COAL		PERCENTAGE IN ORGANIC MATTER OF				HEATING VALUE OF ORGANIC MATTER	EXTRACTED WITH BENZOL AND ALCOHOL	YELDS WITH LOW TEMPERATURE CARBONIZATION				PERCENTAGE IN TAR OF		
		Percentage of ash	Percentage of sulphur	C	H	O	N			Water	Tar	Coke	Gas	Acids	Phenols	Organic bases
Khakhareisky:																
Compact slab	3.98	14.79	0.6	76.5	9.80	11.87	0.83	7,584	4.0	8.0	42.6	19.9	29.5	0.04	1.7	2.02
Lamellated excavation No. 1	5.50	21.4	0.62	78.5	10.73	8.74	1.24	9,104	10.3	14.0	42.0	33.1	10.9	0.2	1.3	1.3
Lamellated excavation No. 6	5.9	37.7	1.0	66.64	9.84	—	—	7,427	12.7	16.8	25.0	50.0	8.2	0.14	2.35	1.68
Bituminous shale (Nasledoff)	8.03	52.7	0.83	63.36	9.71	—	—	7,339	2.55	14.0	12.0	66.4	7.6	0.2	3.42	1.85
Cheremkhowsky (gagat)	1.66	5.29	0.71	81.10	8.34	8.68	1.12	8,325	0.8	5.6	39.1	39.4	15.9	0.5	2.0	2.0
Matagansky	1.26	10.44	2.7	78.69	10.41	7.29	0.56	8,322	1.8	4.8	48.8	20.0	26.4	0.44	1.7	0.3
Sukhokujatsky	4.13	7.78	—	76.82	8.85	12.78	0.79	7,902	1.6	—	—	—	—	—	—	—

(3) All bogheads contain a higher percentage of hydrogen than any of the coals, that have been investigated to the present time.

(4) Low temperature tars from bogheads contain carboxylic acids; as these acids could not form during low temperature carbonization, we must admit that they are constituents of the bogheads.

(5) Low temperature tars from bogheads contain a very low percentage of phenols (about 2 per cent), which means, that there is in the composition of bogheads only a very small percentage of substance, which gives phenols by distillation at low temperature; by this property bogheads differ essentially from all humic coals, which give low temperature tars with a high percentage of phenols (from 25 to 45 per cent).

Regarding the treatment with an alcoholic solution of sodium hydroxide, there is an essential difference between various bogheads. Matagansky and Sukhokujatsky bogheads may be partly saponified by boiling with an alcoholic solution of sodium hydroxide; by such a treatment it is possible to obtain from these bogheads a series of saturated and unsaturated acids with 6 to 20 carbon atoms in the molecule. Other bogheads give by such a treatment either an extremely small quantity of acids (Khakhareisky compact slab), or do not give any of these acids at all (Pobedensky boghead). From this fact we can conclude, that in the formation of the first bogheads, which can be saponified, both processes of polymerization and of anhydrization have taken place, while in the formation of the second bogheads processes of polymerization have taken place almost entirely.

In cases, when we meet with a layer of coal consisting of intermittent light strata of bogheads and coals, the latter present the properties of typical bituminous coals, which are without doubt formations of intermediate character. As a typical layer of such coals, we investigated the Sumpfowy layer from Cheremkhowo. This layer consisted of ten light strata (Fig. 1), from which nos. 2, 4, 5, 8, 9 and 10 present lustrous black good coking coals, while nos. 1, 3, 6 and 7 present "combustible shales." From these combustible shales no. 6 is a typical laminated boghead, which can be very easily split into sheets, and owing to this property, has received from the workmen the name of "devil's skin." The results of the investigation of all these coals are to be seen from Table II. From these results it is possible to arrive at the following conclusions.

(1) The organic matter of combustible shales contains a high

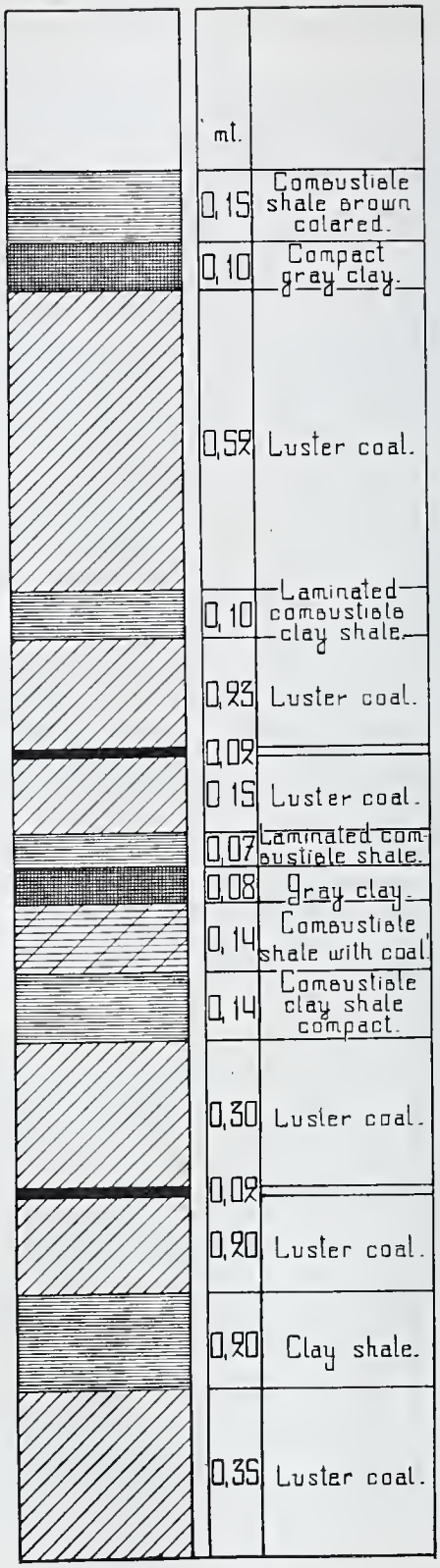

Fig. 1. Cheremkhowsky Mines (Siberia). Layer Sumpfowy

TABLE II

RESULTS OF THE CHEMICAL INVESTIGATION OF COALS FROM SUMPFOWY LAYER OF CHEREMKHOWO (SIBERIA)

Specimen	Moisture	Percentage of ash on dry coal	Volatile products (muck)	Percentage of S on dry coal	Percentage in organic matter of			Bitumen extract with $C_2H_5 \cdot OH + C_6H_6$	Yields at low temperature carbonization of				Composition of low temperature tar in per cent			Composition of low temperature gas in volume per cent						Heating value of organic matter
					C	H	N		Tar	Water	Coke	Gas	Organic bases	Phenols	Organic acids	CO_2	C_nH_{2n}	N_2	CO	CH_4	H_2	
1	5.17	49.53	32.4	0.73	72.05	7.71	1.66	2.0	10.6	10.0	78.4	3.4	0.8	9.0	0.5	9.0	6.4	21.7	2.6	60.3	0	6,955
2	6.64	10.01	47.5	1.56	77.28	5.66	1.52	6.7	16.4	15.9	65.4	6.9	2.7	18.3	0.0	12.1	7.5	1.4	8.2	70.8	0	7,923
3	6.09	56.98	30.9	0.62	66.37	8.26	1.27	1.9	9.9	11.5	78.7	2.6	0.5	7.1	0.4	—	—	—	—	—	—	6,049 (?)
4	8.03	15.92	44.3	2.75	76.97	5.59	1.80	7.0	13.8	13.7	67.7	7.2	3.5	18.8	0.0	—	—	—	—	—	—	7,926
5	6.93	18.86	43.8	2.29	76.85	5.83	1.76	6.8	16.1	13.3	67.1	6.7	3.1	17.0	0.0	10.2	6.5	0.9	6.0	76.4	0	8,005
6	6.11	55.61	37.0	4.67	69.05	9.60	1.00	1.7	16.8	10.5	68.5	6.4	1.2	5.0	0.3	5.8	7.1	20.2	2.7	60.3	3.8	7,386
7	6.13	73.64	25.8	0.85	43.23	10.58	0.76	0.7	2.9	15.8	84.5	1.6	—	—	—	—	—	—	—	—	—	—
8	7.30	13.56	45.7	3.85	75.00	5.51	1.42	6.5	14.8	15.7	67.3	6.4	3.4	17.7	0.0	—	—	—	—	—	—	7,841
9	8.00	14.67	45.4	4.05	75.66	5.54	1.59	6.1	15.0	14.4	66.7	7.1	3.0	18.1	0.0	—	—	—	—	—	—	7,902
10	8.25	15.43	43.5	3.99	73.09	5.42	1.51	6.6	13.1	15.2	69.0	6.2	3.8	17.9	0.0	12.0	6.3	2.4	5.9	73.4	0	7,481

Note: Specimens 1, 3, 6 and 7—combustible shales; specimens 2, 4, 5, 8, 9 and 10—lustrous stone-coals.

percentage of hydrogen (from 8 to 10 per cent), and resembles in this respect the organic matter of bogheads.

(2) The percentage of hydrogen in the organic matter of the black coals is almost as great as in typical bituminous stone-coals.

(3) The combustible shales give, by extraction with a mixture of benzol and alcohol, a very low yield of bitumen and owing to this property, also resemble bogheads.

(4) The black coals give by extraction with the same solvents a comparatively higher yield of bitumen (from 6 to 7 per cent) and owing to this property are distinguishable from compact bogheads.

(5) The "combustible shale" devil's skin, which most resembles bogheads, gives a very high yield at low temperature tar (44 per cent of the organic matter).

(6) The black coals give also a higher yield of tar in comparison with common stone-coals and by this property resemble gaseous and pitch coals.

(7) The low temperature tars from the "combustible shales" contain carboxylic acids and resemble the tars from bogheads.

(8) The tars from the "combustible shales" contain a considerable percentage of phenols (from 5 to 9 per cent) and owing to this property present the first stage of transition to the tars from typical humic coals; the combustible shale "devil's skin," which is of all the investigated combustible shales the most like bogheads, gives tar, containing the least percentage of phenols (5 per cent).

(9) The low temperature tars from the black coals do not contain carboxylic acids; the percentage of phenols in these tars is comparatively low (from 17 to 19 per cent); owing to this property, the tars from the black coals are not typical tars from humic coals and present the second stage of transition to them.

(10) In this layer we consequently do not find typical bogheads or typical humic coals; according to the properties of combustible shales and coals and to the composition of tars obtained from them, we must admit, that we find here a range of gradual transitions from bogheads to humic coals. There is no doubt, that during the formation of this layer a change of vegetation has taken place on the surface of the basin. During one period microplants rich in fatty oils predominated; sediments of these microplants produced the combustible shales which resemble bogheads. During other periods there predominated a vegetation, rich in cellulose and lignin; sediments of these plants produced the black coals. Neither combustible

shales nor black coals of the investigated layer present typical bogheads or typical humic coals.

It is very interesting but at the present time incomprehensible, that by the formation of combustible shales, unsaturated organic acids of microplants were transformed into products of polymerization having cyclic structure and acid nature and have been preserved in this state to the present time; by the formation of black coals, on the contrary, these products of polymerization of unsaturated acids were transformed into bitumen, soluble in organic solvents.

THE CLASSIFICATION OF NORTH AMERICAN COALS

By A. C. Fieldner

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Introduction

Two years ago at the time of the First International Conference on Bituminous Coal, a meeting of representatives of various professional societies, industrial, educational, and governmental organizations, was held here in Pittsburgh to consider what action, if any, should be taken on the classification of North American coals. This meeting was called by the American Engineering Standards Committee because a system for the use classification of coal, proposed by Geo. H. Ashley,[1] had been referred to the Association by the Coal Mining Institute of America. This meeting was well attended and was definitely in favor of taking up the whole question of both scientific and use classification of coals, including all the various ranks from lignite to anthracite. The American Society for Testing Materials was recommended as the sponsor organization to take charge of the work and organize the sectional committee, according to the rules of the American Engineering Standards Association. These rules provide that: "The personnel and composition of each sectional committee shall be authoritative and adequately representative of the various interests concerned in the standard or group of standards, for the formulation of which the sectional committee is responsible."

Following this meeting the American Society for Testing Materials proceeded with the organization of the committee. Invitations to appoint representatives were sent to the various trade organizations interested in the production, distribution, and consumption of coal, and also to professional, scientific and technical societies and to governmental organizations interested in coal classification. The organization meeting of the committee was held in Philadelphia on June 10, 1927. Officers were elected, regulations adopted, and general plans for carrying out the work were outlined.

[1] Ashley, Geo. H. A Practical Classification of Coals. Proc. Coal Mining Institute of America (1923), pp. 29–36. A Use Classification of Coal. Trans. Am. Inst. Min. and Met. Engrs., Vol. 63 (1920), pp. 782–796.

Following this organization meeting, the membership of the sectional committee was completed. The total membership of 28 consisted of eight producers, two distributors, nine consumers, and nine members representing general and scientific interests.

Obviously, a committee of twenty-eight is too large for effective operation. Therefore, three technical committees of ten to twelve members each were organized. These are on Scientific Classification, H. J. Rose, Chairman; Use Classification, W. H. Fulweiler, Chairman; and Marketing Practice, F. R. Wadleigh, Chairman. The Technical Committee on Scientific Classification was requested to formulate a system of coal classification based on chemical and physical properties of the coal, and with reference to origin and constitution. The Technical Committee on Use Classification was charged with developing a system of classification, if possible, based primarily on the uses of coal and commercial practice; this system to be correlated with the scientific system as far as possible and desirable. The Technical Committee on Marketing Practice was formed to collect and collate information on commercial practice for the benefit of the other two committees.

The first meetings of the technical committees were held on November 17, 1927, and the first informal progress reports were submitted to the sectional committee at the annual meeting held on March 28, 1928. These reports showed that each committee had made a satisfactory beginning in planning programs and assembling necessary data for carrying out their work. It is believed that a brief review of this first year's work will be of interest to this international congress and may arouse discussion and possibly pave the way for coöperation in an international system of classification.

WORK OF THE TECHNICAL COMMITTEE ON SCIENTIFIC CLASSIFICATION

The Technical Committee on Scientific Classification accepted the instructions of the executive committee and agreed that a scientific system for the classification of coal should be developed primarily on the basis of chemical, physical, and geological considerations. The work of the committee was organized under the following sub-committees:

Sub-committee I: On nature, location, and mode of occurrence of types of American coals. M. R. Campbell, Chairman.

Sub-committee II: On origin and composition of coal, and methods of analysis. A. C. Fieldner, Chairman.

Sub-committee III: On present and proposed systems of coal classification. H. J. Rose, Chairman.

Mr. Campbell,[2] Chairman of Sub-committee I, presented a comprehensive description of the United States Geological Survey basis of classification of coal by ranks at the first international conference in 1926. This system of classification by rank recognizes the various stages through which coaly matter passes in its progressive transformation from peat to anthracite. Unfortunately, nature has not set up any definite sub-divisions in this scale, therefore, the limits of the different ranks are arbitrary and overlapping of properties can not be avoided. However, Campbell has given extended study to this scheme of classification and has developed a general

TABLE I

LIST OF CLASSES OR RANKS RECOGNIZED

CLASS OR RANK	EQUIVALENT TERM IN PRESENT UNITED STATES GEOLOGICAL SURVEY CLASSIFICATION
A	Peat
B	Lignite
C	Sub-bituminous
D	Bituminous, low rank
E	Bituminous, high rank
F	Semi-bituminous
G	Semi-anthracite
H	Anthracite
I	Super-anthracite

plan of classification which has been used by the United States Geological Survey and the United States Bureau of Mines for coals of the United States. This scale includes the nine classes or ranks of coal and allied mineral substances given in Table I.

The application of chemical and physical criteria to these classes will require extended work by the committee. Proximate and ultimate analyses, calorific values, and physical properties are all of importance. For a beginning, Campbell has confined himself to the proximate analysis and the calorific value of the dry ash-free coal, and to certain physical properties, such as the tendency to

[2] Campbell, Marius R. American Coal Supply. Its Quantity, Quality and Distribution. Proc. of the Int. Conf. on Bit. Coal, Carnegie Institute of Technology, pp. 5–64.

TABLE II

ANALYTICAL LIMITS AND PHYSICAL CRITERIA FOR VARIOUS RANKS OF COAL

CLASS OR RANK	PROXIMATE ANALYSIS PERCENTAGE IN ASH-FREE COAL			CALORIFIC VALUE OF ASH-FREE COAL	PHYSICAL PROPERTIES AND OCCURRENCE
	Moisture	Volatile matter	Fixed carbon		
				B.t.u.	
A	90–80	—	—	—	Peat
B	50–32	25–30	28–37	6,400– 8,300	Slacks freely on weathering; non-coking; northern part of Great Plains and Gulf coastal area
C	32–12	32–38	36–50	8,550–11,800	Slacks considerably on weathering; non-coking; western States and possibly certain coal fields, Iowa, Illinois, Missouri, western Kentucky, and Indiana
D	12– 5	39–42	49–53	12,000–13,600	Slight or no slacking on weathering; may be coking; all coal-bearing States except the Dakotas
E	5–35	40–22	55–75	14,000–15,000	No slacking properties; often coking; most abundant in Appalachian field, but also found in most coal-bearing States
F	26–23	23–15	74–82	15,200–15,300	Friable; coking; nearly smokeless; central Pennsylvania; New River—Pocahontas field; Fort Smith field of Arkansas and Oklahoma
G	Fuel ratio (F.C./V.M.) from 4.0–10.0				Less hard and less lustrous than typical anthracite; near Lykens, Bernice, and Carbondale in Pennsylvania; Meadow Branch field of West Virginia; and Valley field of Virginia
H	All Pennsylvania anthracite with fuel ratio over 10.0				Pennsylvania anthracite
I					Resembles graphite; Rhode Island and southern Massachusetts. Local deposits due to metamorphism caused by volcanic dikes and sills

slack on exposure to the atmosphere. Table II gives a summary of these criteria.

The foregoing criteria of classes of coal in the rank scale apply to the ordinary ulmic or woody type of coals. Similar criteria will be worked out for cannel and boghead coals. Three types of coal are recognized, namely: (1) woody, xyloid, ulmic, or humic coals; (2) canneloid or spore coals; and (3) boghead or algal coals. The type represents the nature of the original coal-forming vegetation, and the rank represents the degree of transformation or metamorphism.

Sub-committee II, on origin, composition, and methods of analysis, is the authority on testing methods, both in describing existing methods and in developing new methods. This committee will be the source of information on the interpretation of old analyses, and will advise on what properties determinations can be made. Existing analytical data will be assembled by this committee. A preliminary report has been made which gives the probable errors and limits of accuracy of the American Society for Testing Materials standard methods of analysis, and comments on the effect of changes made from time to time in the standard methods. Experiments are now in progress on the development of an accelerated slacking test for low-rank coals and lignites. These coals usually have a high moisture content and disintegrate or slack after mining. The slacking tendency has been considered characteristic of sub-bituminous coals and lignite in the United States Geological Survey method of classification.

Briefly, the slacking test consists of air-drying a 1,000-gram sample of 1- to 2-inch lumps at 30° to 35°C. for twenty-four hours, and then immersing the lumps in water for one hour; the water is then drained off, and the sample is again air-dried for twenty-four hours. The amount of disintegration is determined by sieving on an 8-inch wire-mesh sieve with $\frac{1}{4}$-inch square openings, and weighing the undersize and oversize. The percentage of undersize is a measure of the slacking characteristics of the coal. Results of preliminary tests are promising; a sample of Texas lignite gave 97 per cent fines; a Wyoming sub-bituminous coal 84 per cent; an Iowa low-rank bituminous 24 per cent; and high-rank bituminous coals, which are known not to slack, gave 3 to 10 per cent fines.

One of the most important problems facing the analytical committee is the question of whether to use for classification the simple, dry, ash-free analytical values as ordinarily determined in com-

mercial coal analyses, or the "unit" values as proposed by Parr. Strict accuracy also demands special correction of the hydrogen and carbon determinations to eliminate that part of these elements which is derived from water of constitution in shale or clay and from carbonates. Tideswell and Wheeler,[3] and also Seyler,[4] favor such corrections. Our committee recognizes the theoretical justification in favor of the corrections, but it also appreciates the practical difficulties of getting commercial laboratories to adopt the more complicated procedures. The committee is therefore approaching this question with an open mind, and proposes to make a thorough investigation of the problem.

It has been suggested that instead of correcting the analyses for the errors introduced by high ash content, the inorganic matter be removed as far as possible by a float-and-sink process, oil flotation, or acid extraction, before making the chemical analysis. Such a procedure should reduce the ash content to such a low amount that the error could be disregarded for classification purposes. The committee desires to obtain suggestions on this question of ash correction or removal in connection with classification.

Sub-committee III, on present and proposed systems of classification, is making an exhaustive study of the more important methods which have been proposed for coal classification with a view to correlating coals in each of the principal systems of classification.

Almost all scientific systems of classification are based on either proximate or ultimate analysis of the coal, or on a combination of proximate analysis and calorific value. Among these, the principal systems under consideration by the sub-committee are the following:

1. On basis of proximate analysis, calorific value, and physical characteristics. United States Geological Survey[5] and Ashley systems.[6]

[3] Tideswell, F. V., and Wheeler, R. V. Pure Coal as a Basis for Classification. Tech. Pub. No. 104, Am. Inst. Min. and Met. Engrs., March, 1928.

[4] Seyler, Clarence A. The Classification of Coal. Paper presented at New York meeting, February, 1928, Am. Inst. Min. and Met. Engrs.

[5] Campbell, W. R. Prof. Paper 100 A, U. S. Geol. Survey (1917–1922); Proc. of the Int. Conf. on Bit. Coal, Carnegie Inst. of Tech. Pittsburgh, Pa., pp. 11–16.

[6] Ashley, Geo. H. A Practical Classification of Coals. Proc. Coal Mining Institute of America (1923), pp. 29–36. A Use Classification of Coal. Trans. Am. Inst. Min. and Met. Engrs., Vol. 63 (1920), pp. 782–796.

2. On basis of "unit coal" volatile matter calorific value. The Parr system.[7]

3. On basis of ultimate analysis. The Seyler[8] and Ralston[9] systems of plotting carbon, hydrogen and oxygen on a triaxial diagram.

4. On basis of physical and burning characteristics. The German or Continental European system.

GEOLOGICAL SURVEY CLASSIFICATION BY RANK

The various ranks assigned to American coals in progressive order, beginning with the youngest stage in coal formation, are, peat, lignite, sub-bituminous, bituminous, semi-bituminous, semi-anthracite, anthracite and super-anthracite. The bituminous rank is again subdivided into low-, medium-, and high-rank bituminous coal; and the semi-bituminous into low-, and high-rank semi-bituminous coal. The criteria for classification are proximate analyses, calorific values and certain physical characteristics of the coal; the proximate analysis is sufficient to differentiate the ranks from bituminous to anthracite, but physical characteristics are essential, in addition to the proximate analysis, for identifying sub-bituminous coals and lignite.

Figure 1 shows Campbell's graphic representation of the average ash-free proximate analysis and the calorific value of the dry ash-free combustible matter of the various ranks. The upper diagram shows the progressive increase in the calorific value from peat to low-rank semi-bituminous coal. At this rank the calorific value attains a maximum, and then decreases with further increase in rank due to the elimination of hydrogen that has taken place in the anthracitization of the coal by temperature and pressure in the earth's crust.

It is seen from these diagrams that the percentage of fixed carbon is the outstanding factor which shows the relative rank. Metamorphism of peat to coal consists of the gradual elimination of water and volatile matter. In the early stages water elimination pre-

[7] Parr, S. W. The Classification of Coal. Jour. of Ind. and Eng. Chem., Vol. 14 (1922), p. 919.

[8] Seyler, Clarence A. Proc. South Wales Inst. Engrs. (1900), Vol. 21, p. 483, et seq.; reprinted in Fuel in Science and Practice (1924), Vol. 3, pp. 15–26, 41–49, 79–83.

[9] Ralston, O. C. U. S. Bureau of Mines, Tech. Paper No. 93 (1915).

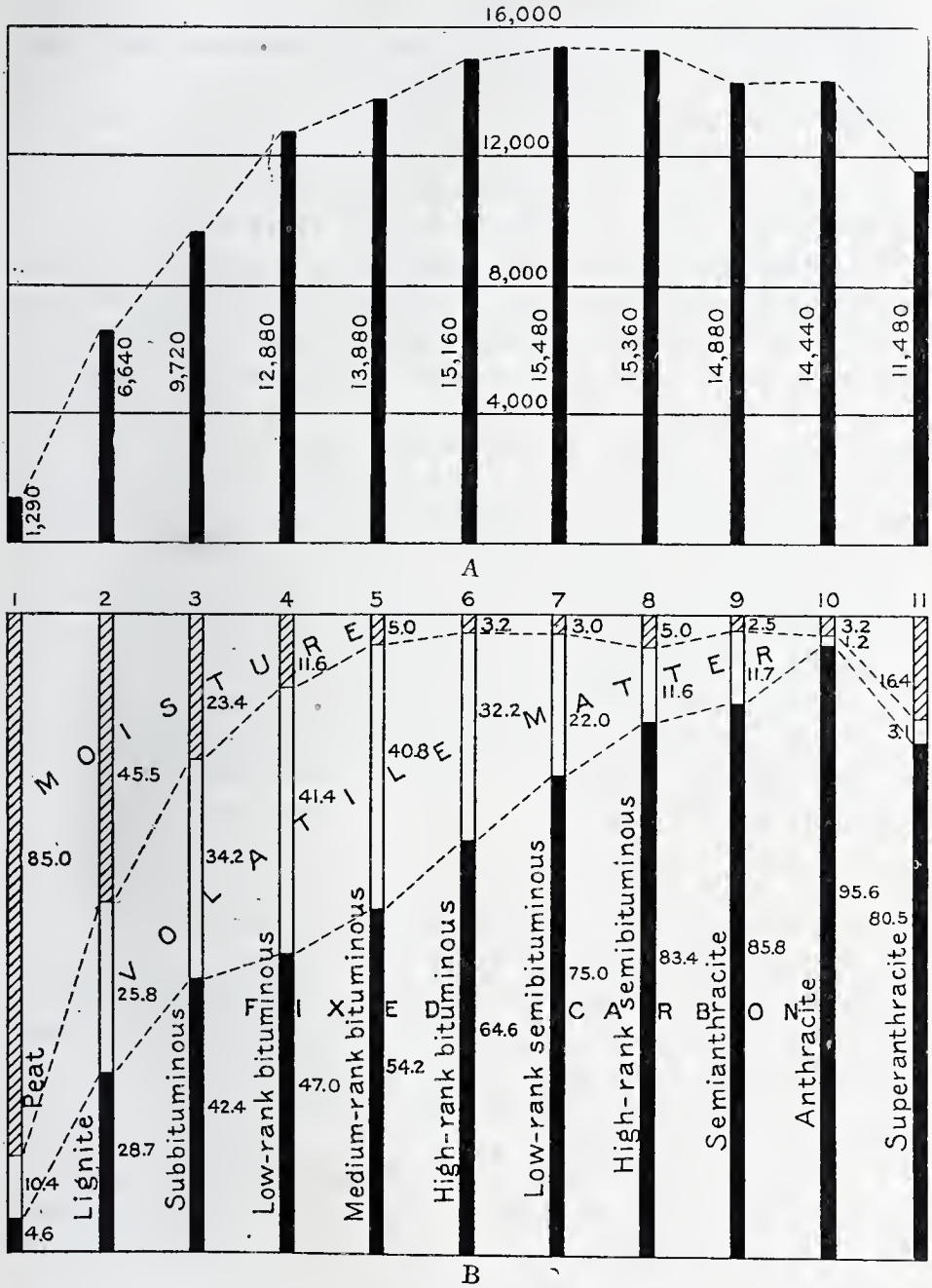


FIG. 1. DIAGRAMS SHOWING THE AVERAGE ANALYSIS OF THE VARIOUS RANKS OF COAL

Diagram B shows the ash-free proximate analysis, and diagram A the moisture-and-ash free heating values expressed, in B.t.u. (After M. R. Campbell.)

dominates and in the later stages volatile matter removal is the principal factor. Of course, not all of the volatile matter is combustible; part of it, especially in the early stages of metamorphism, is carbon dioxide and water. Geologists usually term this progressive metamorphism of coal to higher rank, "carbonization," since it is indicated by an increase in fixed carbon and also of total carbon in the coal.

The term "fuel ratio," i.e., the ratio of fixed carbon to volatile matter expressed by the symbol FC/VM, is generally used by American geologists in setting the boundaries of the ranks of coal. This ratio applies very well to coals of medium-bituminous rank and higher, but fails in the lower range due to the fact that the volatile matter factor decreases with decrease in rank. A glance at the lower diagram of Figure 1 shows that the percentage of fixed carbon in the coal as mined but calculated free from ash may be preferable to the fuel ratio for indicating rank. It may be applied throughout the entire range of coals.

The upper diagram of Figure 1 also shows that the calorific value of the coal as occurring in the bed but calculated free from ash indicates rather definitely the proper position in the scale of rank for those coals which rank below semi-bituminous. This change is due to the progressive increase of moisture with decrease in rank as shown in the lower diagram.

The system of classification based on the proximate analysis and calorific values, as shown in Figure 1, is supplemented by certain physical criteria, especially in differentiating between lignite, sub-bituminous, and low-rank bituminous coal. Lignite disintegrates or "slacks" readily on exposure to weather. So does sub-bituminous coal, but not as rapidly or as completely as lignite. Low-rank bituminous coal slacks slowly and not completely. This slacking is directly proportional to the bed moisture in the coal and can be predicted from the moisture content.

The Geological Survey system of classification by rank on the basis of proximate analysis and physical characteristics is practical and easily applied. It has the disadvantage of any system in that the boundary lines between ranks are difficult to choose; for there are no sharp boundaries—one rank merges into another. The boundaries must be arbitrary to a considerable degree. It is also true that not all coals with the same proximate characteristics are identical in properties. The volatile matter and fixed carbon do not occur in

coal as such, but are the results of heat treatment. To obtain comparable results these determinations must be made under definitely standardized conditions. For the last 15 years these determinations have been definitely standardized, and results by this standard method are strictly comparable; but unfortunately, before this period, standardization as to temperature of determination was not definite, and therefore all results in the literature are not comparable. Also, the composition of the volatile matter varies with the composition of the coal. This factor introduces another variable. Hence we must expect some variation in the qualities of coals with the same fixed carbon percentage.

Ashley's System of Use Classification

Ashley's system of use classification also is based on proximate analyses and physical factors, and is essentially similar to the Survey system, with slightly different groupings and analytical limits for the groups. The "use" part of the classification consists of assigning limits of ash and sulphur within the different ranks, thus indicating the grade of the coal. Ashley also gives representative ultimate analyses of the different classes of coal, and specifies certain physical characteristics, such as, "structure," "hardness," coking properties, flaming properties, etc. A new system of nomenclature is also provided.

Classification from Ultimate Analysis

From a chemical point of view, ultimate analysis appears superior to proximate analysis as a basis for classification. The ultimate analysis gives the chemical composition of the coal substance. The dominating chemical elements composing all plant substances are carbon, hydrogen, and oxygen. These also are the elements that compose coal; ash-forming material, sulphur, and nitrogen may be regarded as fortuitous, since their amount in coal has nothing to do with the rank or class of coal. Therefore the relative proportions of carbon, hydrogen, and oxygen in the coal, calculated free from ash, sulphur, and nitrogen, should have an important relationship to the composition of the original organic deposit, the degree of metamorphism, and the properties of the coal itself.

This idea was first advanced by Regnault in 1837, and was later

amplified and applied to European coals by Grüner[10] and by Seyler[3] and to American coals by Grout[11] and by Ralston.[9] Ralston's work is of special interest in the classification of American coals. In 1915 he published a Bureau of Mines technical paper on "Graphic Studies of Ultimate Analyses of Coals," in which he showed that the samples of coal represented in Bulletin 22 of the Bureau of Mines (where the first 10,000 analyses made by the Geological Survey and the Bureau of Mines are reported) and variously described, according to the classification developed by former workers, as anthracite, semi-anthracite, semi-bituminous, bituminous, sub-bituminous coal, and lignite, when plotted according to their ultimate analyses fall on the ternary diagram of carbon, hydrogen, and oxygen into certain definite fields that overlap to only a small extent. Figure 2 shows Ralston's diagram of trilinear coördinates. It will be observed that all of the analyses lie in a thin, narrow band extending across the lower part of the diagram, and that beginning with graphite on the extreme left at about 98 per cent carbon the various ranks of coal arrange themselves in the order of descending rank with decreasing carbon content and increasing oxygen content. Carbon and hydrogen are the principal variables in the upper ranks down to semi-bituminous coal. From semi-bituminous to lignite the hydrogen content is fairly constant and the oxygen and carbon vary. Carbon varies continuously throughout the range. Cannel coals, which are rich in spore matter, fall distinctly above the line of ordinary coals due to their higher hydrogen content. Nevertheless, they also fall into progressive ranks due to metamorphism. Their difference from the ordinary "humic" or "woody" coals is due to a difference in original plant material forming the coal. Ralston states that in plotting the analyses of coals from the Bureau's records he used different marks to distinguish the different ranks of coal according to the accepted classification that was assigned to the coal by the field man sending in the sample. He found that each rank of coal usually fell into its proper group with little overlapping. This fact is remarkable in view of the fact that the system of classification used was that of the Geological Survey based on proximate analysis. In view of this agreement it would appear logical that both systems have a scientific basis and that one can be translated into the other.

[10] Grüner, E. and Bousquet, G. "Atlas Générale des Houilléres," deuxieme partie, texte (1911), p. 16.

[11] Grout, F. F. Economic Geology, Vol. 2, (1907), pp. 225–241.

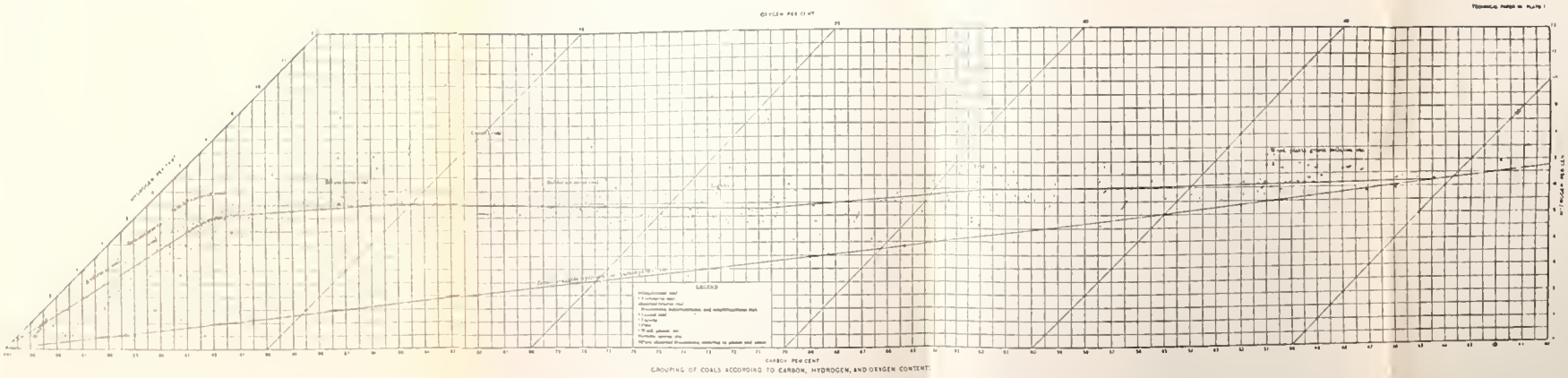


FIG. 2. GROUPING OF COALS ACCORDING TO HYDROGEN, CARBON AND OXYGEN.
(After Ralston, Technical Paper 93, U. S. Bureau of Mines.)

RELATION BETWEEN CLASSIFICATION BY PROXIMATE ANALYSIS AND ULTIMATE ANALYSIS

A very important deduction from Ralston's trilinear diagram is that a definite relation exists between the ultimate analysis of coal and its calorific value. Although this fact was previously known, since calorific values may be calculated to within 1 or 2 per cent by Dulong's formula, the diagram shows this relation more definitely and enables one to determine the ultimate analysis directly from the graph if one knows the volatile matter and the calorific value. Figure 3, the relation of the calorific value and volatile matter of coals to the ultimate analysis, shows intersecting "isocal" and "isovol" lines obtained by drawing them through points representing coals of equal calorific values and likewise through points representing coals of equal volatile matter. Corrections for sulphur were applied to the calorific values before plotting them. This form of graphical representation permits of applying either ultimate analyses or volatile matter plus calorific values to the identification of a given class of coal, or if the classification criteria are given in terms of percentage of carbon, hydrogen, and oxygen, the equivalent criteria for this class can be determined in terms of volatile matter and calorific value. This comparison is advantageous since proximate analyses and calorific values are more generally available than ultimate analyses.

PARR'S CLASSIFICATION

Professor Parr* has utilized this relation in his system of classification based on volatile matter and calorific value. Figure 4 shows Parr's system in which the calorific values in B.t.u. are plotted as ordinates and the percentages of volatile matter as abscissas. Both values are given in terms of "unit coal," i.e., calculated free from moisture and ash and corrected for sulphur and water of hydration of shaly matter. This system has the merit of simplicity as compared to the ultimate analysis system, but of course does not give as much differentiation of various kinds of coal. Nevertheless, its close relation to the ultimate analysis system and its ease of application justify its incorporation in any scientific method of classification.

* Parr, S. W. The Classification of Coal. Jour. of Ind. and Eng. Chem., Vol. 14 (1922), p. 919.

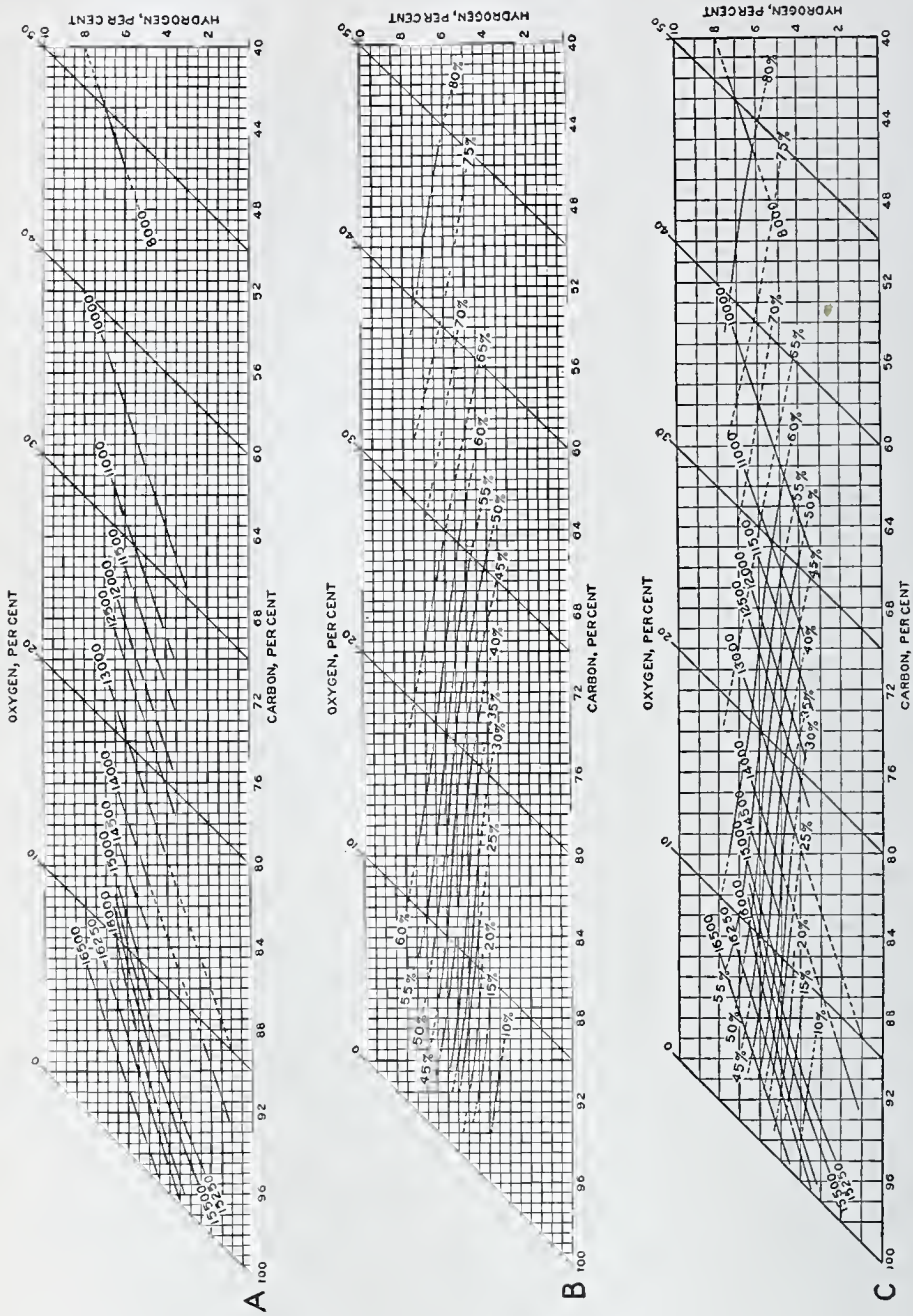
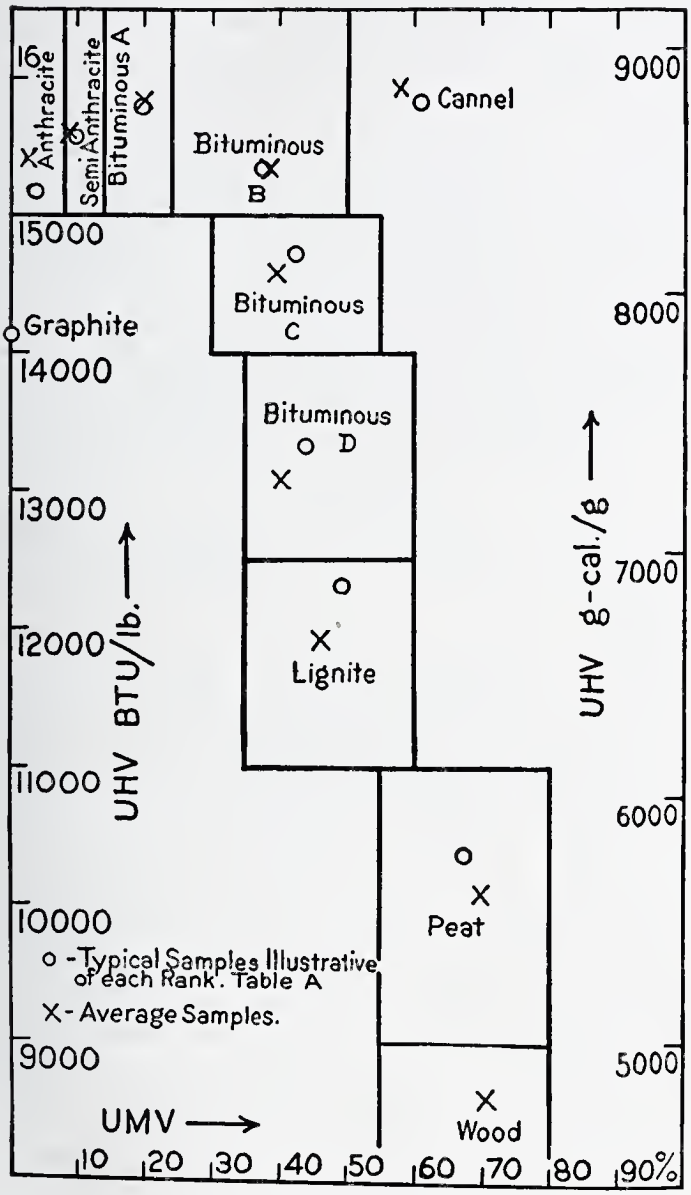


FIG. 3. RELATION OF THE CALORIFIC VALUE AND VOLATILE MATTER OF COALS TO THE ULTIMATE ANALYSIS

(From Technical Paper 93, U. S. Bureau of Mines.) *A*. Curves showing relation of the calorific value of coals to the ultimate analysis. Each curve is drawn through points representing coals of equal calorific value. *B*. Curves showing relation of volatile-matter content of coals to the ultimate analysis. Each curve is drawn through points representing coals of equal volatile-matter content. *C*. Diagram showing relation of isocalorific and isovolatile curves.



Classification of solid fuels.

FIG. 4. PARR'S SYSTEM FOR THE CLASSIFICATION OF COAL
(From International Critical Tables)

CONTINENTAL EUROPEAN CLASSIFICATION

The classification of European coals appears, from the literature, to be based largely on the behavior of the coal in a platinum crucible coking test and on the physical conditions of the solid residue from this coking test. Coals are classified as sand, sinter, or caking coals according to the degree of fusing or caking that has taken place in the solid residue of the volatile matter determination. Sand coals do not fuse or soften on heating and yield powdery sandy residue. Sinter coals form a sintered residue in which particles are fritted together but have not fused to produce a porous structure. Caking coals fuse on heating, and form a porous solid button.

Further classifications are made on the basis of relative length of flame of the coals on burning and on the relative tar yields on distillation. These distinctions are covered by the terms short or long flame coals and lean or fat coals. It also seems customary in European practice to classify according to certain uses, as for example, coking coal, smithing coal, and gas coal are common commercial terms. There is, of course, no standard practice of European classification, but from my review of the literature, I should place the various class terms in the order of rank of coal shown in Table III.

TABLE III

CONTINENTAL-EUROPEAN CLASSES OF COAL ARRANGED IN ORDER OF RANK

1. Peat
2. Brown Coal
3. Lignite
4. Flame coal; long-flame sand coal; gas-rich sand coal
5. Gas coal; long-flame fat coal; gas-flame coal
6. Coking coal; smithing coal; fat coal
7. Ess coal; semi-fat coal; short-flame fat coal
8. Sinter coal; semi-lean coal
9. Anthracite; lean sand coal; lean coal

Grüner[12] and subsequent investigators[13] have proposed limits of

[12] Grüner. Ann. des Mines (1873), p. 169. Dingler Polyt. Jour., Vol. 213, p. 244.

[13] Regnault. Ann. de Chim. et Phys., Vol. 66, p. 337.

Bauer. Beitrage zur chem. der Trockenen Distillation der Steinkohle. Rostock, (1908), p. 27.

Kukuk. Broockman's classification in "Unsere Kohlen," 2nd Ed., p. 21.

Strache, H., and Lant, Richard. Kohlenchemie (1924).

Wirth, F. Brennstoff-Chemie. Verlag of Geo. Stilke, (1922).

Schläpfer, P. Private communication (1924).

ultimate and proximate composition to the different classes, so that correlation can be made with American systems of classification.

CORRELATION OF SYSTEMS

Mr. Rose's sub-committee is now engaged on correlating the various classification systems, and in developing graphic methods for comparing them. It is evident that the ultimate analysis systems of Seyler and Ralston and the Parr system can be correlated in this manner; likewise the proximate analysis methods such as that of the United States Geological Survey and the one proposed by Ashley can be compared to the others, perhaps less directly, but nevertheless with sufficient accuracy to permit of setting up limits for those groups of coals which have similar characteristics, so that each coal may be placed in any system. From these comparisons the committee hopes to work out eventually the best combination of analytical and other criteria for a scientific classification of coal.

WORK OF THE TECHNICAL COMMITTEE ON USE CLASSIFICATION

The technical committee on the use classification of coal is charged with making a study of the possibilities in the development of such a classification, if desirable, possible, and equitable, based principally on the uses of coal and commercial practice, but also correlated with scientific classification in so far as is thought desirable or possible. One of the objectives of this committee is to determine how far the scientific classification may be of use in commercial practice. Another objective is to secure data on the different uses for coal and the requirements for these uses. To attain this end, sub-committees were appointed to obtain data on the following uses and types of coal:

1. Gas making: water gas, coal gas, and producer gas
2. Coke making
3. Coal used in the brick and tile industries
4. Coal used in the cement industry
5. Coal used in the metallurgical industry
6. Smithing coal
7. Railroad coal
8. Stationary steam generation
9. Domestic bituminous coal
10. Domestic anthracite coal

Considerable information has been assembled by the sub-committee on gas coals, coal for water-gas generators, and coal for producer gas. Specifications and desirable characteristics for these classes of coal are outlined in the first report of this sub-committee.

The sub-committee on coals for stationary steam generation also has submitted a comprehensive preliminary report on the desirable characteristics of coals for hand firing, for different types of stokers used in steam power plants, and for pulverized fuel combustion. Obviously, no hard-and-fast rules can be laid down for such coals, since costs and available supply are important factors.

The task before the use classification committee is a large one, and several years will be required to assemble all the needed information.

WORK OF THE TECHNICAL COMMITTEE ON MARKETING PRACTICE

The technical committee on marketing practice is to collect and correlate information on marketing practice with reference to classification, and for the benefit of the other two technical committees. In order to collect data on marketing practice and classifications now in use, sub-committees were appointed to cover the various marketing areas of the country. These areas are as follows:

1. Anthracite (all markets)
2. New England
3. Coastwise (tidewater), export and bunkers, and Atlantic States inland
4. North
5. South
6. Southwestern
7. Rocky Mountains
8. Pacific Coast
9. Central (east of Mississippi River)
10. Southern inland
11. Lakes and Northwest
12. Canada, Eastern and Central
13. Canada, Western

Of these sub-committees, three have already completed comprehensive reports, namely, those on anthracite, the Pacific coast, and the Rocky Mountains region. The data being obtained are proving to be particularly valuable to the use classification committee.

SUMMARY AND CONCLUSIONS

In summarizing the program of the sectional committee on the classification of coal the following important considerations are being kept in mind:

1. Coal should be classified primarily on the basis of its intrinsic chemical and physical properties. These properties involve the origin, composition, and constitution of the coal.

2. Use classification should be secondary to scientific classification and should be correlated with the scientific classification as far as possible.

3. Scientific classification depends on two primary factors, first, the composition and type of the original coal forming vegetation, and second, the degree of metamorphism or coalification of the vegetable residue.

4. The first factor is described broadly in the type of the coal, as xyloid, canneloid, or boghead; the second factor in the progressive rank of the coal as expressed in the series from lignite to anthracite.

5. The criteria to be considered for classifying under these two general factors are proximate and ultimate analyses, calorific values, microscopic examination, extraction with solvents, reaction with reagents, and destructive distillation.

In conclusion, it may be said that the work of the various committees is now well under way. The project is of great magnitude and of the highest importance. Uniform classification should be a great aid to a better understanding between seller and buyer, and should result in directing each class of coal into the use for which it is most valuable. This great international conference is evidence that many new uses for coal are impending. These must be taken into consideration in revising our present classifications. In behalf of the committee I wish to enlist your interest and coöperation in the project. The committee needs the help of research, educational and industrial organizations in collecting data on coal and in solving the many problems that arise in correlating analytical characteristics with constitution and use of the coal. We are indeed fortunate in having the valuable coöperation of the Mines Department and National Research Council of Canada. This arrangement will insure uniformity in classifying the coals of North America.

The organization of separate committees on scientific and use classifications promises to do away with much unprofitable argument

in the progress of the work. It provides clean-cut objectives for each group, and permits the scientists to develop their ideas unhampered by commercial considerations. On the other hand, the engineers and commercial men concerned with producing, distributing, and using coal are able as members of the use classification committee to work out their ideas with the advice of the scientific men who compose a minority on the committee. The scientific committee consists chiefly of chemists, geologists, and paleobotanists, but there is also included a minority of practical fuel engineers to keep the scientists from wandering into the field of impracticability.

After each of the two technical committees has reached a satisfactory conclusion in the work of classification, and has submitted a report, the entire committee will probably take steps to harmonize "use" and scientific classification as far as is possible. It is not unlikely that the final result will be a simple system of classification, both scientific and useful.

DISCUSSION

RALPH H. SWEETSER (Assistant to First Vice-President, The American Rolling Mill Company; Chairman of the Iron and Steel Division, American Institute of Mining and Metallurgical Engineers): In discussing the able address of Dr. Fieldner on "The Classification of North American Coals" one should first give recognition and appreciation to the clear and comprehensive statement of the beginnings and of the progress of a tremendous undertaking that originally was intended to be confined to the North American continent, but possibly now may be extended to an international scope and become world wide in its application. Dr. Fieldner has presented the aims and methods of procedure of the American Engineering Standards Sectional Committee on the Classification of Coal and has briefly explained the work accomplished by that committee up to date.

This review of the first year's work of the Sectional Committee furnishes much for discussion. The very magnitude of the undertaking makes it all the more imperative that the basis of the work of each sub-committee be fundamentally right. At this stage of such a gigantic coöperative work, involving research, nomenclature, theories, classifications, scientific investigations, commercial aspects and geological formations, it would be very easy and yet very disastrous, if the methods and bases of any of the sub-committees should err even a little. We are dealing with a natural product and not a manufactured article. It is necessary therefore that we should deal with this product—coal—in its natural state, and in the condition in which it is found. It is further necessary that the analyses entering into the deliberations of this very comprehensive committee should be made of samples obtained under conditions recognized as standard, and with a record of the coal seam and the part of the seam sampled that would be without dispute as to the authenticity

of its description. From my own personal observations and from the reading of reports of analyses of different coals, I am convinced that much of the past records of coal and analyses are unreliable for the purpose of drawing conclusions and for the purpose of classifying the coals.

Those of you who have been used to the reports, even of our Bureau of Mines and a great many of the coal investigators, have had doubts as to the value of the analyses made from samples of which we do not know the record. There is one danger we will have to watch.

Dr. Fieldner in behalf of the committee has asked for the interest and coöperation of the delegates to this Second International Conference on Bituminous Coal. In the list of investigators and men interested in this work of classifying coals, I do not find my own classification. My approach to this subject is not as a chemist, or a geologist, or a paleobotanist, or as a fuel engineer, but as an iron and steel man—a blast furnace man, if you please. With the background of iron ore mines and blast furnaces, coal mines and coke ovens, it is natural to view this work of classifying coals in the light of what has been done in classifying and evaluating iron ores.

I felt a little bit lonely when I wrote this but after I heard Dr. Baker speak this morning I felt right at home. Those of us who heard him speak will recall that he said the greatness of the iron and steel industry of the city of Pittsburgh was based on coal. I feel very much at home in approaching this question of coal from the viewpoint, or standpoint, of an iron and steel man.

Dr. Fieldner in speaking of the classification from ultimate analysis, has said that "The dominating chemical elements composing all plant substances are carbon, hydrogen, and oxygen. These also are the elements that compose coal; ash forming material, sulphur and nitrogen may be regarded as fortuitous since their amount in coal has nothing to do with the rank or class of coal. Therefore, the relative proportions of carbon, hydrogen and oxygen in the coal, calculated free from ash, sulphur and nitrogen, should have an important relationship to the composition of the original organic deposit and degree of metamorphism, and the properties of the coal itself." This statement presupposes that the theory of the formation of coal from vegetable matter is correct. This theory has not been proved, and is still only a theory. I question the consistency of the scientific attitude of mind that would include hydrogen and oxygen in connection with carbon in the classification of coals and leave out all the sulphur and nitrogen.

On these charts that we have seen here on the screen this afternoon I noticed that one of the Russian coals had four times as much nitrogen as some of the other Russian coals. I noticed also that one of the coal analyses showed about 75 per cent ash and 10 or 12 per cent water. Are we going to ignore all of that and classify the coals just with what carbon is left?

There is also apparently an attempt to classify certain coals apart from their water constituent, which would, to my mind, be as unfair and as unscientific as to classify Siderite ($FeCO_3$) as an iron ore by first separating it from the CO_2 gas which determines that this particular iron ore is a carbonate and not an oxide of iron. We do not take the water out of Turgite before classifying it as an iron ore. Hematite (Fe_2O_3) is an oxide of iron and is classified as Hematite or "specular iron." If we add one part of water to two parts of

Hematite, we have an entirely different iron ore in its physical characteristics, its specific gravity and its richness as an ore of iron. Apparently all the difference between the two ores is the water of combination. Pyrite is an iron ore and a combination of iron and sulphur, but we do not take away the sulphur before we classify the ore. We may separate the sulphur from the iron before we make use of pyrite as a source of pig iron, but it must first be changed into an oxide of iron and an oxide of sulphur before it can be commercially used as an iron ore. It is also necessary that certain coals must be divided into the carbon constituent and water constituent before they can be commercially used as fuels or sources of carbon. It is unfair and it is unscientific, however, to classify these coals *after* this separation has taken place.

I object strenuously to the method of classification of coals according to calorific power if the calorific value is to be obtained after the inherent water in the coal has been separated from the carbon and hydrogen in the coal. The presence of this water determines the characteristics of that particular coal in much the same way as water in various combinations with oxides of iron determine whether an iron ore is Hematite, or Limonite, or bog ore. The classification of these minerals as iron ores is based on the construction of the ores in their natural combinations and not after the water has been driven off by heat.

It is well known to by-product coke oven men that certain formations of sulphur in coking coals will follow the coal through the coke ovens and into the coke, and will remain combined with the carbon until separated by the intense heat and fluxing action in the hearth of a blast furnace. It is yet to be demonstrated that sulphur "has nothing to do with the rank or class of coal."

There is also an attempt to classify coals on their ash-free basis. Obviously it would be wrong to classify a coal that would include the extraneous earthy matter found in the partings and impurities of coal as taken from the coal seam, such as clay and slate, but to classify coals absolutely ash-free seems to be inconsistent. The "inherent" ash should be determined and studied in its relationship to the physical and chemical effects on the quality and characteristics of the coals.

I could not help thinking, when I saw the charts that Dr. Fieldner showed, that there would be a tendency—if I may use that expression—to force the analyses and the apparent similarity to fit some theory. It seems as though we must be careful not to force these things, although there may seem to be a very close similarity between the coals as they are separated from their water and from their sulphur and from their ash. I think that should be very carefully studied.

The details of samples of the coal seams and the details of preserving the coal samples until the time of final analysis, are questions for the various subcommittees to decide. I will not discuss them here.

It is fitting, however, to call attention to the necessity of recognizing the fact that many veins of bituminous coal in this country consist of several separate venters of coal sometimes very much alike in character and analysis and sometimes entirely unlike.

The final conclusions of the entire committee will be based upon the findings of the technical sub-committees.

Dr. Fieldner, in his summary, says that coal should be classified primarily on the basis of its intrinsic chemical and physical properties. He emphasized that point and I wish to emphasize it. You will notice it says "upon its intrinsic chemical and physical properties."

It does not seem fair to give coal samples too much heat treatment, as we say in the steel business, before you classify them. That is something that will have to be guarded against. It is therefore entirely within the jurisdiction of this International Conference on Bituminous Coal to call attention to the danger of taking into the considerations of the various committees any data based on the analyses of samples of coal unless the records of the samples give positive evidence that they were representative of the part of the particular coal seam sampled, and that the samples were kept intact and in their original condition up to the time of their analysis.

A great many of the records of coal analyses have been evidently taken from samples of coal that were perhaps put into a bag and shipped into the laboratory and analyzed, no knowing how, long after the sample was taken. Those of us in the coke oven business know that if you leave certain coals outside in the stock pile they take on a lot of oxygen and the character of that coal is absolutely changed from what it was originally. Those things will have to be guarded against.

I suppose the sub-committees have taken proper precautions to have the coal samples kept in their original condition.

Dr. Fieldner expresses the hope that the final result will be a simple system of classification, both scientific and useful. Speaking as an iron and steel man, I hope that this simplifying classification will center around the one basic element in coal, carbon, just as the classification of iron ores centers around the one basic element, the iron.

GEORGE H. ASHLEY (Geologist of the State of Pennsylvania): Mr. Fieldner's comprehensive and balanced paper lays an excellent foundation for a more critical discussion of certain phases of the subject.

First: Coals are like men; no two are exactly alike yet it is possible to divide them into classes. The classification to be made depends on the use to be made of it. Candidates for a job may be classified according to their intelligence tests, or coals may be classified according to their B.t.u. If, however, a man is looking for a dancing partner or a chemist is looking for a coal to be hydrogenated, the above basis of classification may not be of interest.

Scientifically, most objects can be classified best by their origin: races of men—Mongolian, Caucasian; kinds of coal—cannel, boghead, splint, etc. Then these broad general classes are usually subdivided on characters derived from their subsequent history: nationalities of men, class or rank of coals. Still further subdivisions may be made upon individual differences, such as groups of men—carpenters, bricklayers; or of coals—low sulphur and high sulphur. The final grouping depends upon the use to be made of the classification.

Considered in this broad way there is no reason why one classification of coal may not serve all the demands of the scientist and the user of coal. On the other hand, nothing short of such a classification into kinds, classes or ranks and groups will satisfy either the scientist or user of coal.

Coals differ in not less than a score of physical characters quite aside from the chemical characters—such as in specific gravity, color, hardness, color and length of flame, fracture, plant constitution, structure, resistance to weathering, and so on. As a rule, coals of the same kind and in the same class are fairly similar in physical as well as chemical composition, although they may differ in percentage of ash, composition of ash, fusion point of ash, or other characters that form the basis of subdivision into groups and that may be of very great importance in coal utilization. No single series of classes such as several of those mentioned by Mr. Fieldner can possibly take account of all of these differences.

Second: Any classification that starts out by rejecting the moisture of coal can be neither scientific nor practical. Continued studies indicate that water is quite as much a part of cellulose or other vegetal matter as it is of watermelon or of human beings. The fact that dry coal subjected to moisture at a given pressure and vapor tension will reabsorb a definite quantity of moisture which is characteristic of each coal should of itself indicate that the water is a constituent part of the coal. When cellulose is heated the carbon, hydrogen, and oxygen come off as H_2O, CO_2, CO, CH_4, and H, etc., with carbon left free. Studies indicate, however, that originally all are combined in unknown ways including all of the hydrogen and carbon. The heat merely serves to crack the heavier compounds, setting free lighter gaseous hydrocarbons and leaving fixed carbon. If we remove the H_2O before starting our study, why not also remove the CO_2? Neither add to the value of the coal. Unfortunately CO_2 begins to come off before all of the H_2O has disappeared, and CO begins to come off before all of the CO_2 has been driven off. To start out by eliminating the moisture of the coal means we have thrown away the key to the classification of the younger or lower rank coals; for the chemical changes that give rise to the lower ranks of coal consist largely of distilling off the moisture. On the other hand most of the ash and sulphur are not inherent in the coal but accidental and incidental and therefore used only in group classification in this discussion.

Third: Mr. Fieldner's paper shows that there has always been a strong tendency to classify coals on a basis of the ultimate analysis, which is almost like trying to judge a picture in an exhibit by the mineral colors used. Coal does not consist of the elements but of hydrocarbon compounds. Following its first deposition coal is subjected to bacterial decay, to burial under the weight of later rock material that may be thousands of feet thick, to earth pressures and movement such as exist at all times but which may become very active at certain times, accompanied by jointing, and often by crushing and fracturing. Coal may be subjected to the near presence of igneous rock, etc. But notice that the tendency of all these forces is to drive off in succession H_2O, CO_2, CO, CH_4 and other gases of this group; then hydrogen, leaving in the end fixed carbon. In brief, these earth forces act on the original coal in very much the same way as heat acts on coal when it is placed in a retort; the same gases are driven off though in different proportions and at different rates. In other words nature produces the various ranks of coal by a process almost exactly simulating the laboratory procedure in making a proximate analysis. Granting this, it is evident that a proximate analysis simply dis-

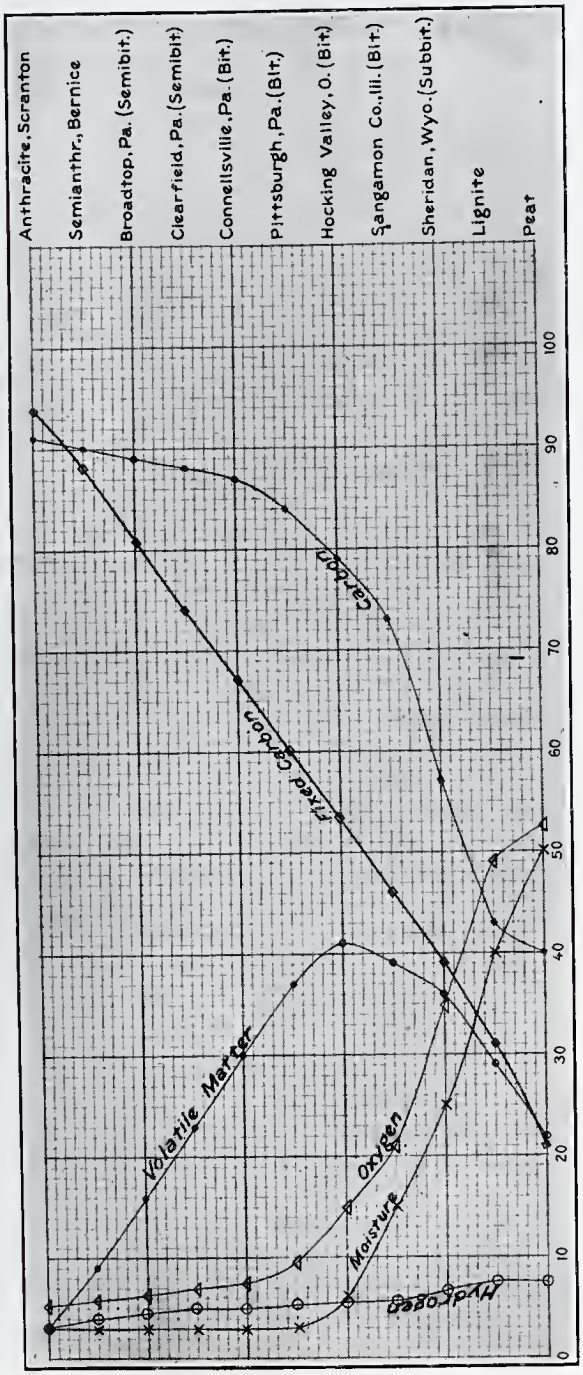


FIG. 5. ANALYSIS FOR THE CLASSIFICATION OF COALS.

covers how far nature has gone by finding out what is left after the natural process of distillation. A proximate analysis simply continues and completes the process of nature. Therefore entirely aside from the labor or cost or other factors it is believed that a proximate analysis makes the best foundation for a classification of coals.

This is still further brought out on the accompanying chart (Fig. 5) which shows, for a selected series of coals, the total carbon, hydrogen, oxygen, moisture, volatile matter, and fixed carbon. It is obvious at a glance that of these, fixed carbon stands in a class by itself in uniformity of spread through the whole series of coals. Hydrogen shows little change from bottom to top. Moisture is constant for all coals about the rank of Pittsburgh coal. Oxygen and total carbon change but little for the ranks about Pittsburgh coal. Volatile matter which changes rapidly for the high rank coals doubles back on itself with the low rank coals. Adding volatile matter and moisture together, however, gives us a measure of the removal of total volatile matter by nature and gives the exact complement of the fixed carbon (in the ash, nitrogen, sulphur-free sample).

To measure the extent of the devolatilization of coal for the purpose of establishing classes or ranks we may therefore use either the percentage of fixed carbon (in the ash, nitrogen and sulphur-free sample), which is a single figure spreading from 20 to 95, or—to save computing coals to the ash-free basis—I suggest using the ratio of fixed carbon to moisture plus volatile matter. This gives a non-overlapping, well-spread series that clearly distinguishes the several ranks of coal. The coals listed on the chart, while originally selected without reference to any of the schemes here presented, prove to represent about equal increments of loss of volatile material or in gain of fixed carbon. The following table shows the ratio of fixed carbon to the total volatile values of the coals shown on the chart. This may be called the "coal ratio" to distinguish it from "fuel ratio" long in use. For the upper coals it will be very close to the fuel values of those coals. The lower coals, however, succeed each other in proper order as they do not in a fuel-ratio classification.

Coals divided into classes by coal ratio

$$\text{Coal ratio} = \frac{\text{fixed carbon}}{\text{volatile matter—moisture}}$$

Lignite under	0.50
Low rank, sub-bituminous coal	0.50–0.75
High rank, sub-bituminous coal, or low rank, high volatile bituminous coal	0.75–1.00
Medium rank, high volatile bituminous coal	1.00–1.25
High rank, high volatile bituminous coal	1.25–1.75
Medium volatile coal	1.75–2.50
Low volatile coal	2.50–3.50
Higher rank, low volatile coal	3.50–5.50
Semi-anthracite	5.50–8.00
Anthracite	8.00

Fourth: I am here concerned mainly with a simple scheme for subdividing coals according to rank. In so doing I wish to emphasize that this is only one part of a general classification scheme that takes second place to the primary classification of coals in accordance with their origin; and that under each class of coal, as they may be divided according to rank, should come a series of sub-classifications based on differences of ash, sulphur, nitrogen, fusing point of the ash, or other elements that may enter and influence the character of the coal or its interchangeability in use.

It should be distinctly understood that the suggested ratios in the table above are not intended to be final, but are given simply as a working basis, to be shifted as further studies of the coals may indicate is desirable or necessary, as the table has not been subjected to any detailed study on my part.

R. E. GILMORE (Superintendent, Fuel Research Laboratories, Department of Mines, Canada. This discussion was not read but presented in writing):

As a member of the Coal Classification Committee of both the American Engineering Standards Committee and the National Research Council of Canada, I wish to commend Mr. Fieldner on the lucid and comprehensive presentation of the material in his paper on the Classification of North American Coals. Mr. Fieldner, you will notice, has taken pains to use the term "North American Coals" and both in print and out of print has requested the close coöperation of all those interested in coal classification. This we in Canada greatly appreciate. That his untiring zeal for more uniformity in classifying coals will not be satiated until he has extended his usefulness beyond North America is evidenced by the belief expressed that a review of the first year's work of the A. E. S. C. Sectional Committee will be of interest to this international congress and may arouse discussion and possibly pave the way for coöperation in an international system of classification.

The estimate of the known coal resources in North America is, I believe; roughly 60 per cent of the world's reserve, of which approximately one quarter is accounted for in Canada. Of Canada's total reserves, less than 10 per cent belong to the class of coking bituminous coals, the remainder being mostly the non-coking sub-bituminous and lignite coals. Of a total Canadian coal production in 1926 of 16½ million tons, the ratio of non-coking to coking coals mined was in the neighborhood of 1 to 3.

Coal statistics presented by Mr. M. R. Campbell in his paper to the International Conference two years ago show that of the total reserves in the United States, considerably over half are non-coking lower rank coals, all of which are to be found west of the 100th meridian. Mr. Campbell pointed out that in the western part of the country containing the non-coking coals, viz., Wyoming, Montana, and the Dakotas, are two great areas of continuous coal-bearing rocks, one slightly larger, and the other twice as large as in the Appalachian region of the east, and that as the supply of the higher grade coals in the east diminish, a corresponding demand for the central and western coals will be felt. Likewise, in Canada, although the bulk of the production of coking coals is in the extreme east and west, the great reserves lie in the province of Alberta on the prairie side of the Rocky Mountains, in which are located over nine-tenths of the country's potential coal resources, and of which 99 per cent

are non-coking sub-bituminous and lignite coals. These comparative figures should be kept in mind when considering the relative importance of the various schemes for classifying coals scientifically on the one hand and according to the various uses on the other hand.

Mr. Fieldner in his paper, as you will notice, has paid more attention to the so-called scientific classification of coal than to the classification according to use. The duty of the Technical Committee on Scientific Classification is, as stated, to formulate a system of coal classification based on chemical and physical properties of the coal with reference to origin and constitution. To the geologist, therefore, belongs the task of correlating the data concerning the location and mode of occurrence of coals; to the microanalyst and paleontologist classification according to types; and to the chemist and allied professions the classification according to composition, chemical constitution, etc. That all criteria, viz., chemical, physical and geological, is essential for a comprehensive scientific classification of coal is evident, and although at times it is seemingly impossible to arrive at a simple system of classification, it apparently is the concensus of opinion of the members of the Scientific Classification Committee that their objective is within reach, if not within sight, in the not far distant future.

The work of the Technical Committee on Use Classification is more complicated and Mr. Fieldner's statement that "several years will be required to assemble all the needed information" is an indication of the magnitude of the task before this committee. The main difficulty in classifying coals according to use is that the cost is often a bigger factor influencing the use of a coal for a given purpose than quality and consequently specifications are liable to change with the price. For this reason it may be neither possible nor desirable to establish definite standard specifications for a given use. However, statements regarding the fundamental characteristics for given uses, outlining possible variation in respect to physical and chemical properties should be of service in directing the different classes of coal into the use for which they are most suited. Of the ten different uses of coal on which separate subcommittees of the Use Classification Committee were appointed to obtain data, it will be noticed that for the most of the uses listed, bituminous coals with varying degrees of coking qualities are required; at least it has been the general belief that only coking coals could be used. Such uses are for coke making, both domestic and metallurgical, smithing coal, railroad coal and domestic bituminous coal. For certain of these uses, as well as for others on the list, non-coking, both higher and lower in rank than the coking bituminous coals, are often in demand, and can be used satisfactorily. For example, the blending of a non-coking coal with a coking coal for the manufacture of coke makes it difficult to draw up specifications for a coal for coke making, and in this connection the definition of the term "coke" in respect to the residue resulting from the carbonization of a non-coking coal is debatable. The definition of coke recently established by the American Society for Testing Materials concerns the carbonized residue irrespective of the kind of coal used, but it is generally a coking bituminous coal or a blend of bituminous coals that are used to produce a coke residue as defined. On this assumption, there is seemingly a need for a definition of the carbonized residue from non-

coking coals and this need is becoming more apparent in connection with the treatment of the lower rank coals by low temperature carbonization.

In Canada, there is a large consumption of non-coking sub-bituminous and lignite coals for many of the uses that formerly called for coking bituminous coals and for household heating purposes these coals are quite suitable. For this reason, in the work of our Canadian Coal Classification Committee we have an additional use, namely, "domestic" (sub-bituminous and lignite) coal. Other uses in which we are specially interested are coals for pulverizing for fuel combustion and railroad coal in both of which the non-coking coals are finding increased use.

Since one of the objectives of the Use Classification Committee is to determine how far the scientific classification may be of use in commercial practice, it is essential that those engaged in this work should keep in constant touch with the different industries using coal for different purposes, and with the preparation of the coal for the market, thus to aid a better understanding between seller and buyer. That such is the case in the furtherance of the use classification program is evidenced by the make-up of the committee comprising engineers and commercial men concerned with producing, distributing and using coal, as well as scientists interested generally in coal. There is a sentence in the early records of the A. E. S. C. Sectional Committee concerning the status and objectives of coal classification to the effect that while it is admitted that no scheme of classification will eliminate the desirability of practical tests, in which a coal is actually used in the equipment for which it is being considered, yet an accurate and dependable system of coal classification will certainly prove to be of great practical value.

That Mr. Fieldner is confident of the outcome of the coal classification work now well under way is evident by the last sentence of the last paragraph of this paper when he predicts that "it is not unlikely that the final result will be a simple system of classification both scientific and useful." In other words a workable classification more useful than ornamental is the task of the so-called practical producers and consumers of the Scientific Classification Committee. Likewise the task of the general-interest scientific men on the Use Classification Committee is to see that a classification useful to all concerned is evolved.

In Canada there are two government departments interested in coal classification matters, the National Research Council and the Department of Mines. These departments are coöperating in bringing together all those interested in coal classification incuding the producers and the large users of coal—American coal in Canada as well as Canadian coal. At the present time it would seem that there will not be great difficulty in arriving at a satisfactory scientific classification With the use of classification, however, the task is more difficult and it may take a long time to arrive at a workable use classification, first among ourselves and then with the American Committee, but the speaker although realizing the great deal of work ahead, is confident that the same can and will be obtained. Should for any reason a final agreement not be the reward, failure is not to be admitted as the mere meeting together and the exchange of ideas between those specially and generally interested is of greatest value.

In conclusion the speaker wishes to take this opportunity of commending the chairmen of the technical committees viz., Messrs. Kose, Fulwetter, and Wadleigh, as well as Mr. Fieldner, the Chairman of the general sectional committee on their work to date, and to assure them again that they have the hearty coöperation of their neighbors to the north in the classification of North American coals.

CHAIRMAN MEISSNER: I would like to ask Dr. Thiessen if he will say a few words.

DR. R. THIESSEN (United States Bureau of Mines, Pittsburgh, Pa.): I have only a few words to say on the subject of boghead coals. Unfortunately I did not get the full significance out of the paper as read. I will have to read it before I can give a discussion on it.

There are a few points, however, on which I would like to make some comments—on the classification of the different coals. Dr. Stadnikoff classifies coals into humic and boghead coals. This differs considerably from a classification as brought out by a microscopic study. According to this the whole range of combustibles must be classified into humic coals, cannel coals, and boghead coals.

For those who are not familiar with the origin of these classes let us recall that the humic coals are those derived mainly from the woody parts of plants, formed in a similar way as peat is being formed in the wooded swamps of today. The cannel coals are derived, under different conditions, chiefly from the spore, waxy, and resinous matter of plants. The plants from which they were derived were much of the same nature as any plant we know, except that they were deposited under such conditions that the humic or woody matter was largely decomposed, leaving mainly the spore, waxy, and resinous matter to accumulate. Again, we can divide the cannel coals into various classes. I cannot go into details now but I will say that we have on the one hand cannel coals— the typical cannel coals, composed predominantly of spores,—and on the other hand those composed predominantly of humic matter. The Germans call the latter "pseudocannel coals." Between these two extremes we have all variations and grades of cannel coals.

The boghead coals are derived from oil algae. That boghead coals are derived from algae has been advocated by the French for some time. Bertrand and Renault argued that they were derived from ordinary algae, such as the volvox. At one time I argued against this theory or origin of the boghead coals very strenuously, because it seemed impossible that ordinary algae could give rise to such bulky bodies as they were supposed to have done, but recently we have found, through the good fortune of having material sent from Australia, an entirely different kind of plant organism that had not been taken cognizance of before, which may have given rise to boghead coal, the oil algae.

The material obtained from Australia is called "green seepage material," and grows in salt lagoons. This material consists of aggregations of blue-green algae. They are very peculiar organisms with thick body walls enclosing relatively small living cell contents. The body wall of this blue-green alga is composed almost entirely of an oil substance. For that reason we have

called the organisms "oil algae." The exact nature of the oil has not yet been determined.

When the oil algae are exposed to the air, the organisms soon die and the living parts, which constitute only a relatively small part of the organism, decompose and leave the heavy walls undecomposed. The accumulation of this is called "coörongite" and represents the peat stage of the boghead coals, or as they are called in Australia, the "kerosene shales."

If the green seepage material or the living oil algae, the coörongite, and the kerosene shale, or the boghead coals are examined microscopically and compared, there are found in them organisms well preserved and so similar to one another that they can scarcely be distinguished. The organism forming the green seepage material, therefore, is very similar to the organism found in the kerosene shale so that there is no doubt that the boghead coals were derived from an oil algae, similar to those now living in the salt lagoons of Australia.

This origin, of course, separates the boghead coals very distinctly and definitely from the cannel coals. The cannel coals are, again, due to their origin, very definitely separated from the humic coals. However, these three are never pure. The boghead coals are often mixed with spores, but contain very little humic matter. The typical cannel coals, composed predominantly of spore-matter, usually also contain some resinous and humic matter, and very often oil algae.

The humic coals, on the other hand, derived mainly from the woody substances, also contain a lot of spore, resinous, and waxy matter. On the whole, these three groups cannot be divided into clean-cut classes, but must be divided into arbitrary division of classes.

As I have said, I did not get the full significance of that paper and I want to study it before I enter into further discussion of it. As far as I could see, it is a very fine piece of work with much good information.

A word on the nitrogen in coal may be in order. I am now thoroughly convinced that nitrogen in coal is not an extrinsic substance but is intrinsic. It is a part of the coal. In our work on the humic substances, which are the main contributants to coal, we find that nitrogen is a part of the humin and has a definite origin. I believe, if sulphur would be examined in the same way, we would find that sulphur also is an intrinsic part of the coal and not an extrinsic part. Also, some of the mineral matter in coal is intrinsic, that is, it is part of the coal molecule as much as the hydrogen, the oxygen, and the carbon are a part of the coal molecule.

THE RÔLE OF HUMIC ACIDS IN THE TRANSFORMATION THROUGH HEATING OF COAL AND IN THE PRODUCTION OF COKE

By Fran Podbreznik, Dr. Ing.

Belgrade

The transformations of coal through heating as well as coking are rather complex phenomena the causes of which are not very well known. The industrial practice of transforming coking coal into metallurgical coke was based, up to within recent years, solely on empiricism. Audibert and Delmas have recently studied this industrial coking process scientifically.

All these transformations of young coal during heating must be connected with the properties of the humic substances, and only by a special study of these substances will it be possible to elucidate these questions somewhat.

We designate as humic substances, that aggregate of compounds met within the coals having lignin as a probable origin. They are: humic acids, humines, and humic compounds.

The dry distillation of humic acids (extracted from coal) frees a rather large amount of water; this can be explained by the formation of insoluble humic anhydrides or of humic lactones.

There is also a freeing of carbon dioxide gas, which is explained by the breaking up of carboxyl groups.

We have studied the decomposition of the crude humic acid (precipitated by hydrochloric acid) and the formation of carbon dioxide.

Up to 150°C. there is no liberation of carbon dioxide. Starting with 150°C. the liberation begins (we have observed this from the turbidity of barium hydroxide solution); towards 200° there is a maximum, while towards 160° the liberation of carbon dioxide ceases.

The artificial humic acids that we obtained from sugar, began to liberate carbon dioxide at about 100°C.

From this we can explain the transformation of the natural humic substances into coal and lignites.

In very young coals there are free humic acids in a proportion not exceeding 15 per cent. These acids are dissolved easily in alkalis (by a slight heating) and in pyridine at boiling temperature (about 120°C.), and even in phenol, as Mr. Soum and I have quite recently

proved. But in the two latter cases there is at the same time a polymerization. In this polymerization we may assume that an internal mono-lactone is formed.

This transformation occurs at about 100°C. and the humic acids which were originally brown become black.

This mono-lactone is black, insoluble in alkalis, and in pyridine, but still partly soluble in phenol. But by prolonged heating in water solutions of soda and of pyridine, there is formed again humic acid, possessing four acid groups saturable by metals.

Thus the pyridine extract from crude humic acids, after drying at 100°C., was only partly soluble in diluted pyridine, but was rendered completely soluble by hot digestion for ten hours.

In addition to free acids there are in young coals up to 50 per cent of humic acids that are more condensed, probably existing as internal dilactones, as we often find them in the alcohol acids.

These dilactones are transformed into humic acids by potassium hydroxide fusion.

But at a higher temperature these humic lactones are transformed into *humic compounds* which cannot be re-transformed into humic acids.

Just as the lactones are condensed (in case of the alcohol acids) into slightly known substances called *oxetones*, so the humic substances (the humic dilactones) are transformed probably into such humic oxetones.

Beginning at 300°C. the humic substances are decomposed with the giving off of different hydrocarbons that are dissociated in their turn and finally yield methane, hydrogen and elementary carbon.

The Coking of Lignites and of Young Coals

All coals have the property of yielding by dry distillation, a residue called coke. This coke has a calorific value appreciably higher than crude coal, and can serve for different industrial uses (reduction, heating and gasification). But the young coals rarely, and the lignites almost never give a coke utilizable in the above manner.

Two kinds of coal can, accordingly, be distinguished; those which give an industrial coke and those which do not. By "coking" is meant the distillation of some kinds of coal with the view of producing *utilizable* cokes for foundry work and for metallurgy.

Juptner, Muck, Rau, Le Chatelier, Parr-Olin, Lewes, Boudouard,

Liey, Hodurek, and Fischer-Schrader have conducted researches on the causes of the coking of certain kinds of coal.

Boudouard was the first to point out the relation between the content in humic acids and the coking power of coals. According to him the humic acids prevent coking. Several authors seek to diminish the coking power by the oxidation of the bitumens.

I have conducted several pieces of research on the coking of French lignites from the Dordogne and Laluque Mines. It goes without saying that the coke obtained at a very high temperature from these lignites can have no metallurgic use, for it remains too brittle and is not homogeneous enough.

The residue that remains in the retort after the dry distillation of the raw lignites (from Dordogne and Laluque), as well as of these lignites freed from bitumen, is only a powder.

But the residue of the dry distillation of lignites, extracted with pyridine, collects in a mass, which is very brittle however, and friable between the fingers.

The residue obtained in the potassium hydroxide fusion, in which the humic acid anhydrides are removed, exhibits during the dry distillation some signs of good coking. The coke obtained is hard and not too brittle.

We have verified this interesting fact:

By leaving in the residue of the potassium hydroxide fusion a small quantity of humic acids in the state of potassium humate (which is solid at the ordinary temperature) the coking proceeds very regularly, the mass fuses (it is probably the humate of potassium that melts) so that the coke remaining is very hard but high in ash.

But if before distillation we add to the coals resulting from the potassium hydroxde fusion a little natural asphalt or natural bitumen (about 8 to 10 per cent of the weight of the coal used), the coking was, in this case just as regular as in the presence of the potassium humate. The coke remaining is no longer high in ash.

These facts can give us an explanation of the phenomena observed during the coking of the lignites.

The lignites are made up chiefly of free humic acids and lactonated humic acids. These acids during the heating, lose water and carbon dioxide progressively. This loss occurs very fast in coking where it is necessary to reach a very high temperature rapidly and it causes a breaking up of the lignites. The gases, by leaving abruptly, disintegrate the structure, and the coke resulting is nothing but a powder.

The case is quite different with the gases resulting from the decomposition of the humic substances at an appreciably higher temperature. These gases are dissociated and deposit elementary carbon in the cavities of the coal, which increases the solidity of the coke remaining.

This decomposition of the mass in coking due to humic acids is perhaps diminished by the presence of compounds which melt at a temperature at which the products of decomposition of the humic acids arise. For in melting, these compounds prevent the rapid escape of the gases, dissolve them partly, and thus avoid disintegration. On the other hand, the compounds which melt bring the whole mass of coal into a semi-fluid state which is the necessary condition for obtaining a good metallurgical coke.

This interpretation must also satisfy those who claim that the oxidation of the bitumens prevents coking. Thus Parr claims that the oxidation of resins in the coal diminishes the power of coking. This is so much the more evident since the resins can be transformed into the products which melt less easily, or into acid products, thus becoming comparable to humic acids in that they give off (by decomposition of the acid group) water and carbon dioxide up to 300°C.

We have succeeded in transforming paraffin extracted from Laluque lignite into a product similar to the humic substances (insoluble in benzine) by a prolonged heating with concentrated soda.

The paraffin thus oxidized becomes black and insoluble, even in the alkalis, but easily decomposable by pyrogenous distillation.

The "Valorization" (Improvement in Value) of Lignites and of Humic Coals by a Preliminary Low Temperature Heating

The lignites being very moist (containing as much as 30 per cent water) and containing a large quantity of humic acids, are not suited for industrial or domestic heating because they disintegrate too easily.

According to our tests explained above, we think that this defect may be overcome by heating these coals beforehand, very slowly to a temperature of 250° to 300°C. so as to eliminate progressively, the water, carbon dioxide, humic acids, a part of the total sulphur (in the form of hydrogen sulphide), and a part of the coal tars. Thus the free humic acids would be transformed into lactone humic acids and

into more condensed products corresponding probably to the humic dilactones and oxytones.

Thus lignites and young coals would be transformed into a firmer combustible, having a greater calorific value, which would no longer disintegrate during heating at a high temperature.

This procedure has been recommended for several years, but industrial research is carried on in a quite empirical fashion.

There should be made, on the contrary, for each kind of coal a complete study of the transformation of these humic substances. In each case there must be determined the quantity of free and lactonated humic acids that it is necessary to transform by slow heating into stable humic compounds, and the quantities of gases and coal tars that may be liberated without injuring the firmness of the residue. Thus, we should have a *semi-coke* of a greater value, easily and economically transported, and utilizable for different kinds of industrial or domestic heating.

THE PHENOLIC SOLUBILITY OF HUMIC ACIDS IN COALS

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and

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It seemed interesting to us to test whether humic substances, considered up to now as soluble only in pyridine and alkalis, could not be rendered soluble by other substances, and, in particular, by phenol. It is known, in fact, that natural lignin (lignine d'origine) is soluble in phenol, either under pressure (Bühler), or even at 90° in the presence of traces of hydrochloric acid (Kalb and Schöler). In applying this last method, we have been able to show that certain humic substances were also soluble in phenol. This property makes them closely allied to lignin, rather than to cellulose and permits adding a favorable argument to the hypothesis of Fischer and Schrader.

In order to discover whether humic acids obained from various sources were all soluble in the phenols, we prepared:

a. Artificial humic acids starting with saccharose, pyrogallol, and protocatechnic acid.

b. Natural humic acids extracted from coals with pyridine, soda, and by potassium hydroxide fusion.

These different acids are totally soluble, when hot, in phenol; it is thus a question of a property common to all.

But are humic acids which in the solid state are soluble in phenol, also soluble in it if they are directly extracted starting with fossil combustibles?

To clear up this point we have studied two coals (charbons) of which one came from the mine Siorac de Bèlves in Dordogne, and the other from the mine Laluque in le Landes, France. Dordogne coal is an old coal, an old lignite. Laluque lignite is, on the contrary, a much younger coal.

We show in Table I the comparative results obtained by phenolic extraction, by exhaustion with pyridine, and by potassium hydroxide fusion. These results are, it is seen, very variable. Pyridine ex-

tracts only humic acids, while potassium hydroxide fusion transforms the more condensed acids (which are, without doubt in the state of lactones) into free humic acids, this transformation being accomplished as well in case of the young coals, as in the case of the older coals. As to phenol, it seems to have an intermediate action; we

TABLE I

NUMBER OF TEST	NATURE OF EXTRACTION	PER CENT OF EXTRACTIBLE (AVERAGE OF 3 TESTS) COALS OF	
		Dordogne	Laluque
1	Phenol (1 hour at 100°)	8.38	35.10
2	Pyridine	6.02	8.98
3	Potassium hydroxide fusion on 2	32.30	39.74

TABLE II

NATURE OF THE SUBSTANCE STUDIED	EXTRACTED PER CENT BY	
	Alcohol 95 per cent	Acetone
Humic acids (extr. phen. beg. coals) of:		
Dordogne	35.2	29.7
Laluque	31.1	43.4
Humic acids (extr. sodium beg.):		
Dordogne	12.7	8.2
Laluque	28.9	31.1
Phenolic lignin of pine	100.0	100.0
Sodium lignin of pine (by precipitation beg. with Kraft paste)	89.9	Not determined
Sodium lignin of pine (by precipitation beg. with black liquors of bleachable pastes)	78.6	Not determined
Metalignin of pine (Barton-Wright)	100.0	100.0

noticed, especially, a marked liberation of humic acids in the cases of the lignites and slightly developed coals.

We have proposed, moreover (*Proceedings of the meeting of the Société des Sciences physiques et naturelles de Bordeaux*, June, 1928) this phenolic method for the determination of humic acids in fossil combustibles.

We have also made a study of the alcoholic and ketonic solubility

of humic acids, and of sodium and phenolic lignins which we sum up in Table II.

From the examination of this table the following conclusions may be derived:

a. The lignins are more soluble in alcohol and in acetone than the humic acids.

b. The phenolic products are, in general, more soluble than the sodium products.

All these substances are, moreover, totally soluble in pyridine; only phenolic lignin gives colored reactions.

CONCLUSIONS

In the present study we have shown that humic acids, substances considered up to this time as soluble only in pyridine and alkalis, can be rendered soluble also in phenol; this property allies them to the lignins, which supports the ideas of Fischer and Schrader, according to which it is probably lignin that has formed humic substances in fossil combustibles through the ages. Phenol acts here not only by dissolving the free humic acids but also by rendering soluble, certain more condensed humic substances, due to a depolymerization, without doubt analogous to that resulting from the potassium hydroxide fusion.

We mention, in conclusion, that the phenolic method, which has been used for the determination of lignin in wood, can be applied with success to the determination of humic substances in fossil combustibles.

RELATION BEWEEN THE FOSSIL COMBUSTIBLES AND THE GASEOUS PRODUCTS RESULTING FROM THEIR DESTRUCTIVE DISTILLATION

By Paul Lebeau

Professor, Faculte de Pharmacie de Paris

Read by Dr. Joseph H. James, Professor of Chemical Engineering, Carnegie Institute of Technology

Fossil combustibles subjected to the action of heat with the exclusion of air are transformed and yield volatile substances and a charry residue to which the name of coke is usually given.

With the same coal, the appearance and the properties of the coke, and the quantity and the composition of the volatile substances, vary with the conditions under which this destructive distillation or carbonization takes place.

In coke plants one can, it is true, produce with a well-planned equipment, when starting with coal or with a mixture of properly chosen coals, cokes of every closely related qualities. The composition of illuminating gas manufactured by the same plant from identical raw materials also varies but slightly.

It cannot be deduced, however, from these statements that destructive distillation is a decomposition following a uniform course. The apparent uniformity obtained in industrial operations is due to the use of the same equipment, the enormity of the quantities worked, the identical conduct of the operations—all conditions that tend to give a sort of average result which is approximately constant.

The complexity of the phenomenon of destrictive distillation is evident quite clearly, however, when in operations in the laboratory, we try to evaluate the weight of the volatile substances that the carbonization of a given combustible produces. This evaluation, of a considerable practical interest, has been the subject of numerous discussions, on account of the differences ascertained in the application of the processes proposed for bringing it about.

We find ourselves in the presence of real difficulties due, to a great extent, to the poor heat conductivity of the majority of fossil coals, a property with which is bound up the influence of different factors, such as the weight, the division of the samples studied, the more or less rapid intervention of the calorific action, the form and the

dimensions of the containers used for the heating, etc., on the value of the results obtained.

In the course of our first studies in the carbonization of fossil combustibles, we recognized that it was possible to diminish the influence of these different factors, and to regulate, to a degree, this pyrogenous decomposition by observing the following rules:

1. Use a sample of a rather small weight in order that it be possible to accept as true that its heating occurs uniformly in the whole mass, so as to reduce the influence of the low conductivity of the charge.

2. Choose for all tests, each time that it is possible, the same state of division of the samples.

3. Have the action of the temperature intervene in a regular and progressive fashion.

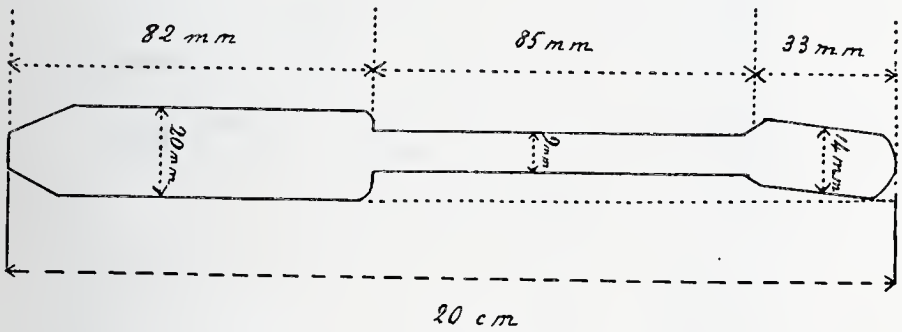


FIG. 1. QUARTZ TUBE FOR CARBONIZATION RETORT

By employing an arrangement of the apparatus that permits collecting all the products liberated, we could hope to obtain useful indications from their examination.

The apparatus that we are now using to study the carbonization of a combustible is comprised of:

1. An electric furnace with a platinum or nichrome resistance, in the central tube of which can be placed two thermoelectric couples and a quartz tube serving as a carbonization retort. The heating tube has a length of 20 cm. and a diameter of 20 mm.

2. The quartz tube represented by the diagram in Figure 1 has a total length of 20 cm. and an interior diameter of 20 mm. The apparatus is composed of an inclined bulb having a length of 33 mm. and an interior diameter of 14 mm., connected with a tube having a length of 85 mm. and a diameter of 9 mm., which is joined to a wider section, the end of which is open, to permit connecting it with the rest

of the apparatus. This latter part of the tube is 82 mm. in length and has a diameter of 20 mm.

3. A bulb condenser of glass that can be cooled to −80° by a mixture of carbonic snow and acetone.

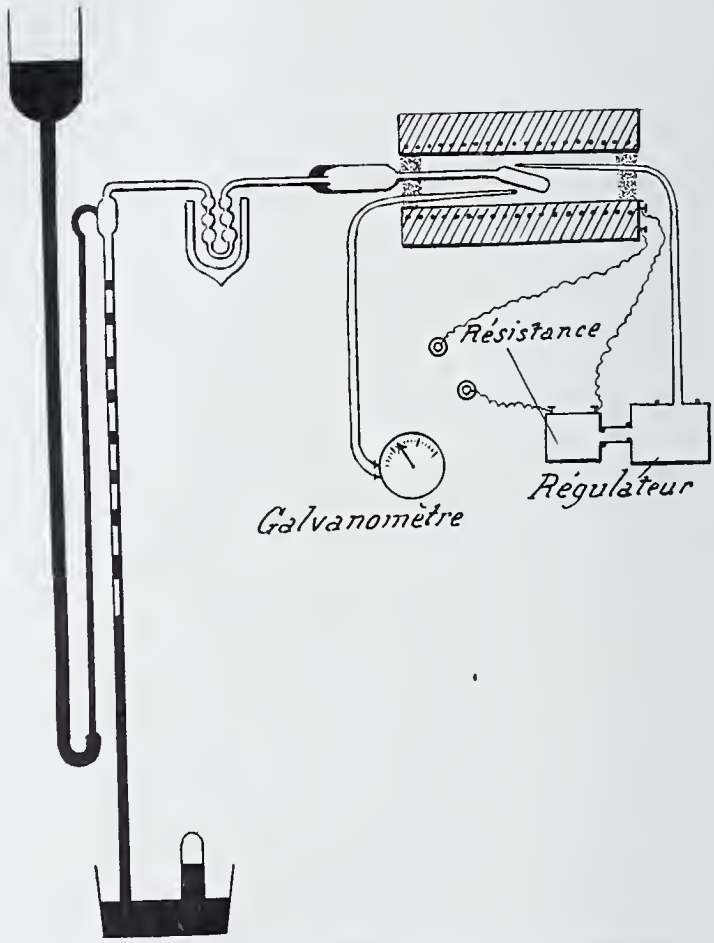


FIG. 2. RESISTANCE, REGULATOR, GALVANOMETER

4. A mercury pump that permits making a vacuum in the whole apparatus and collecting the gases resulting from the carbonization and those non-condensable at −80°.

5. A temperature regulator the thermo-electric couple of which is in the vicinity of the bulb, is inserted in the supply circuit of the electric furnace, in order to maintain a constant temperature during a definite time.

Figure 2 gives an idea of the apparatus adopted. To follow the

different phases of the carbonization of a given combustible, a gram of it is placed in the bulb of the quartz tube. This test sample is selected from an average sample suitably divided.

After having created a vacuum in the apparatus and cooled the condenser to −80°, heat is applied for 10 to 15 minutes to raise the temperature to 100°, a temperature that is maintained for a total time of one hour. The gases given off are constantly extracted during this

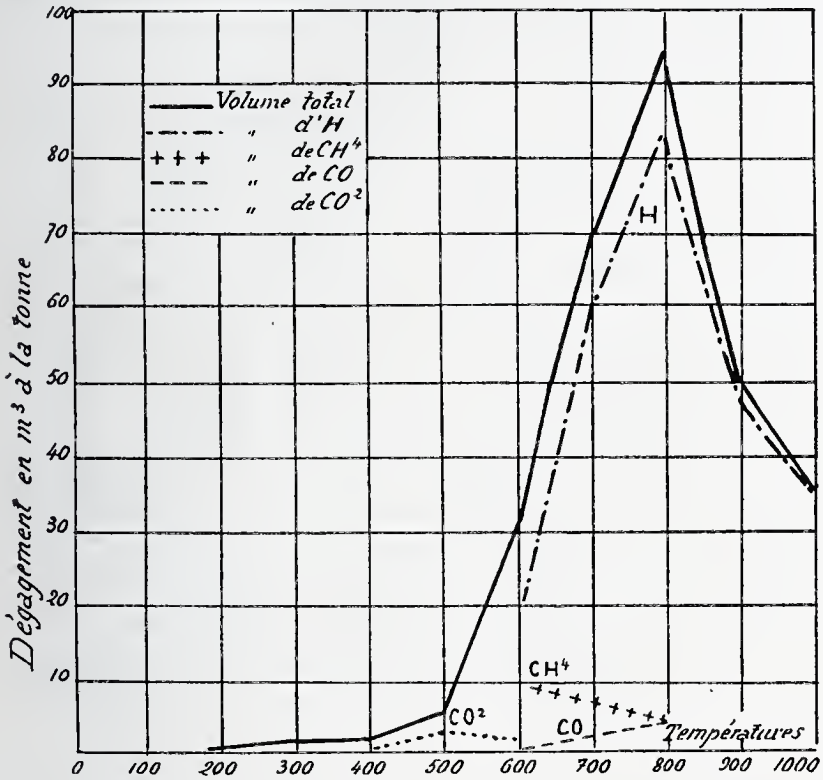


FIG. 3. LIBERATION OF GASES FROM FRENCH ANTHRACITE AT GIVEN TEMPERATURES

time, to be subsequently measured and analyzed. There is brought about, then, under the same conditions, a rise in temperature from 100° to 200°, and the gases continue to be extracted and separated. We go on in a similar manner up to 1,000°, finally having produced 10 samples of gaseous mixtures corresponding to each of the 100° temperature intervals.

In the course of the destructive distillation the coal tars have been deposited at the exterior of the furnace in the widest part of the quartz

tube. It is possible to observe at which temperature they have begun to form, and after the operation their weight can be determined.

In the condenser are found water and the light products whose vapor tension is approximately zero at −80°. With the aid of water, certain soluble gases are partially retained, especially ammonia and hydrogen sulfide.

The gaseous mixtures collected lend themselves to really precise determinations. The measure of their volume and their quantitative analysis furnish useful information that enables one to draw graphs

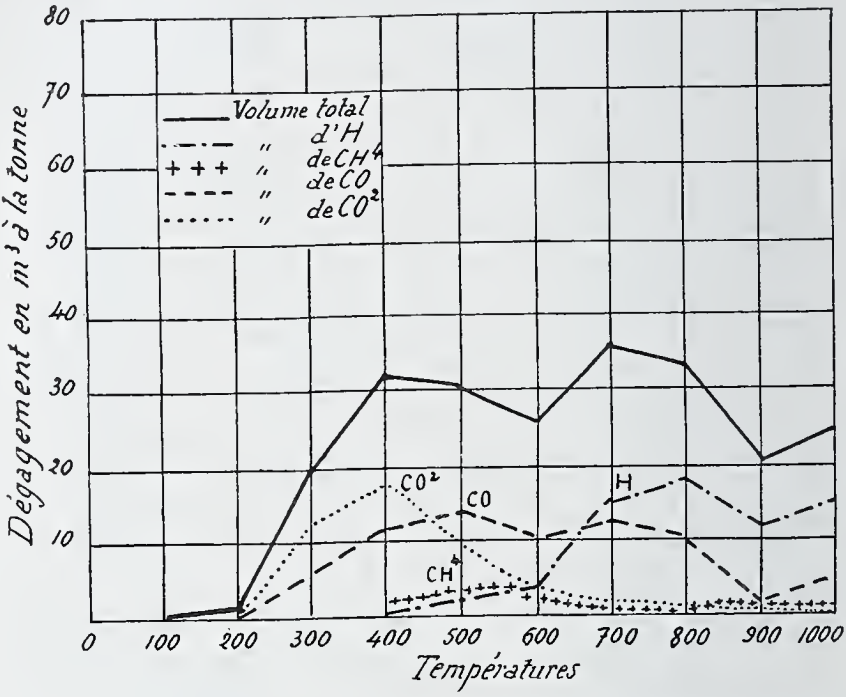


FIG. 4. LIBERATION OF GASES FROM SACCHAROSE AT GIVEN TEMPERATURES

which well represent the progress of carbonization and which can be considered, moreover, as really characteristic of a given combustible.

One can, for example, measure by ordinates, for each extreme temperature of a line taken as an abscissa, the volume of the gaseous mixture collected, and those of its different constituents. Here is, by way of illustration, what such a representation shows for a French anthracitic coal coming from the neighborhood of Alais in the Departement of Gard. (See Fig. 3.)

We shall return later to the interpretation of these graphs, and shall at this point dwell only on the remarkable constancy of the results. The graphs corresponding to repeated tests of the same combustible are almost exactly superposable.

The application of this process to the study of the carbonization of well defined chemical compounds leads to interesting verifications and shows still more clearly its value.

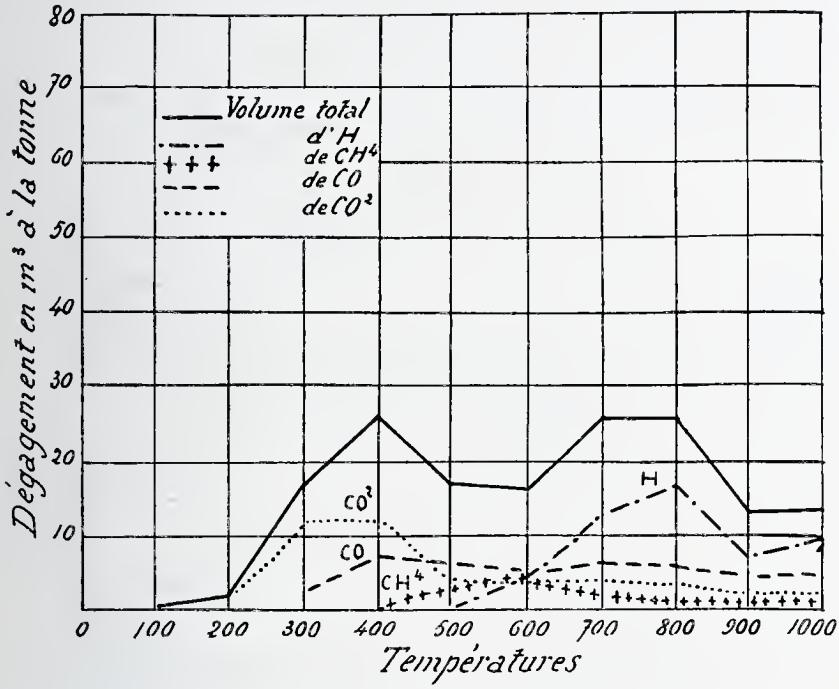


FIG. 5. LIBERATION OF GASES FROM GLUCOSE AT GIVEN TEMPERATURES

Because the formation of fossil combustibles results from transformations undergone by cellulose, lignin, and carbohydrates, which are the principal constituents of plants, we thought it would be interesting to study the carbonization of a few sugars. It is known that many of these carbohydrates, whose compositions are established, are sometimes very abundant in certain plants and that they often arise in the disintegration of more complex molecules, such as those of cellulose.

The results observed with the saccharose $C_{12}H_{22}O_{11}$ are represented by the graphs of Figure 4. The unbroken line that corresponds to the volume of gases liberated for each extreme temperature of the

lines representing temperature changes of 100°, presents a distinct maximum at 400° and another in the zone of 700° to 800°.

The principal gaseous constituents are hydrogen, carbonic anhydride, and carbon monoxide. The maximum emission is at 800° for the first of these gases, at 400° for the second, and at 500° for the third. Methane exists in small quantities in the gaseous mixtures beginning with 400°.

The total volume of the gaseous products reaches 225 cubic meters to the ton (the ton was chosen as a unit to permit a more easy com-

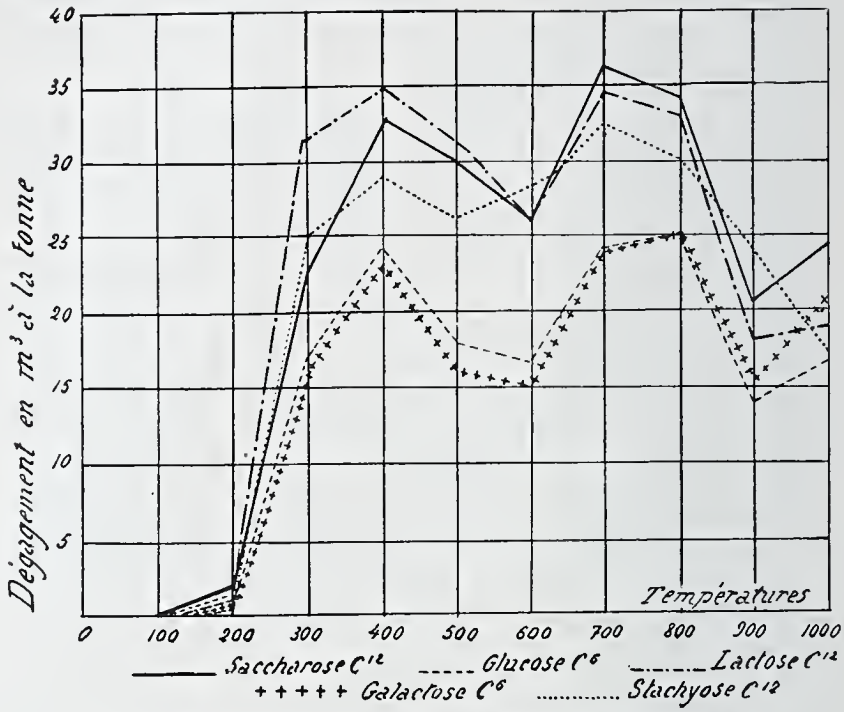


FIG. 6. LIBERATION OF GASES FROM FIVE SUGARS

parison with the numerical data commonly used in the coking industry). The coke residue amounts to 30 per cent, which leaves 70 per cent for the volatile substances. No coal tar is formed.

Glucose, $C_6H_{12}O_6$, gave the graphs of Figure 5, whose appearance brings to mind, by a sort of parallelism, those of saccharose, as well for the total volumes of the gaseous mixtures as for those of their different constituents.

An important difference appears in the total volume of the gases which is only 157 cubic meters per ton. The quantity of coke is also

much less: namely, only 14 per cent. Substances resembling coal tar are not formed.

Stachyose, $C_{18}H_{32}O_{16}$, yielded a total gaseous emission up to 1,000° of the same order of magnitude as C_{12} a product resembling saccharose, but we observed the production of 4 per cent of coal tar, a formation of tar that increases with carbohydrates of greater molecular weights. The same singular points are found again in the graphs.

We have brought together in Figure 6 the graphs of the total volumes of five sugars whose carbonization we have studied. We see here almost a perfect identity for the two C_6 sugars, glucose and galactose, as well as for the two C_{12} sugars, saccharose and lactose. For stachyose, the divergences are slight, and the general direction is preserved.

TABLE I

	VOLATILE SUBSTANCES	COKE	COAL TAR	VOLUME OF THE GASES IN CUBIC METERS PER TON
	per cent	*per cent*	*per cent*	
Glucose	85	14	0	157.38
Galactose	84	16	0	156.78
Saccharose	70	30	0	225.18
Lactose	80	20	0	228.18
Stachyose	74	22	4	213.56

The numerical data collected in Table I show that for the two C_6 sugars, the total gaseous volumes collected up to 1,000° are approximately equal. The case is the same with the two C_{12} sugars. For stachyose the volume is slightly less, which is in relation with the production of tar.

The percentage compositions of the total gaseous mixtures were established for three of these sugars: glucose, saccharose, and stachyose. In spite of the differences between the molecular weights, these percentage compositions are similar enough. We were able to verify this every time that it was a question of compounds of comparable composition.

Marked differences appear between the graphs representing the evolution and the distribution of the different constituents at temperatures corresponding to this thermic fractioning of destructive distillation. At 400°, for example, the content of the gaseous mix-

tures in carbonic anhydride decreases, while the content in carbon monoxide increases with the increase of the molecular weight.

It is thus established that carbonization regularly carried out, under perfectly defined conditions, can furnish useful information on the nature of the molecules destroyed in this way. It was necessary to demonstrate this fact well in order that it be possible to appreciate the value of this process of investigation for the study of fossil combustibles.

We shall sum up very briefly the results obtained concerning the two principal constituents of woods: cellulose and lignin.

The graphs of the celluloses coming from diverse plant species present among themselves the same analogies as those of the sugars that we have just examined. Their general appearance remains very

TABLE II

CONSTITUENT OF THE GASEOUS MIXTURE	PERCENTAGE COMPOSITION OF THE TOTAL GASEOUS MIXTURES FOR:		
	Glucose	Saccharose	Stachyose
Hydrogen	31.30	30.10	27.72
Carbon monoxide	29.80	33.18	33.10
Methane	8.71	8.58	9.75
Ethane	1.27	1.06	1.17
Ethylene	0.80	0.97	0.68
Carbonic anhydride	28.12	26.00	27.20

much the same. The differences observed here are still quite distinct between the total gaseous volumes given off up to 1,000°.

A cotton cellulose gave 123 m^3. of gas to the ton, while that of poplar gave 259 m^3. Divergences of the same order were found in the weights of the coke yielded; namely, 13 per cent for reed cellulose, and 31 per cent for oak cellulose. On the contrary, the percentage compositions of the gaseous mixtures are very nearly the same.

Taking as a basis the observations made upon the sugars, we can conclude that the celluloses of different plant species—celluloses that we have taken care to isolate by the same process—are chemical species of very comparable composition, but that they are distinctly differentiated by their molecular condensation.

The graph of a cellulose always comprises a very sharply marked maximum at 400°, corresponding to the most abundant freeing of carbonic anhydride and of carbon monoxide, and another very much

less accentuated one at 700°, in relation with the greatest evolution of hydrogen.

It was difficult for us to obtain lignins that could really be considered as a well-defined chemical species, and we observed a few divergences in the results for lignin from the same plant, depending on its mode of preparation. We could recognize that their graphs no longer presented the maximum at 400° as those of the celluloses, but that the production of gases was especially important in the zone 700° to 800°.

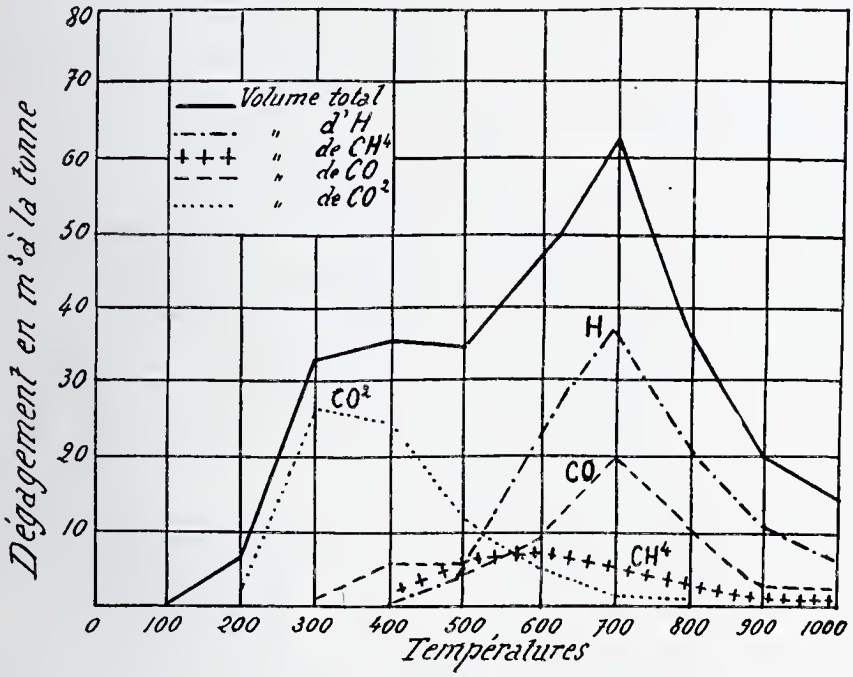


FIG. 7. LIBERATION OF GASES FROM PEAT OF FERTE ALAIS, SEINE ET OISE

Numerous tests relating to the carbonization of woods gave graphs often characteristic of their species, and they present always the two characteristic singular points of their most abundant constituents: viz., the maximum at 400° of cellulose, and the maximum at 700° to 800° of lignin.

This method which we have designated by the name of thermic fractioning during destructive distillation, appeared to us to be very fruitful in its application to the study of the combustion of fossil fuels, and capable of being used as one of the best means of fuel characterization, thus giving valuable information for their rational

utilization. We shall set forth now the general results of the researches that we have conducted for several years on this important subject.

1. Peats. The peats are considered as fossil combustibles of relatively recent formation. They are grouped by taking as a base the nature of the plants which gave rise to them, or their geological situation. They could, thus, be classified either into moss peats or

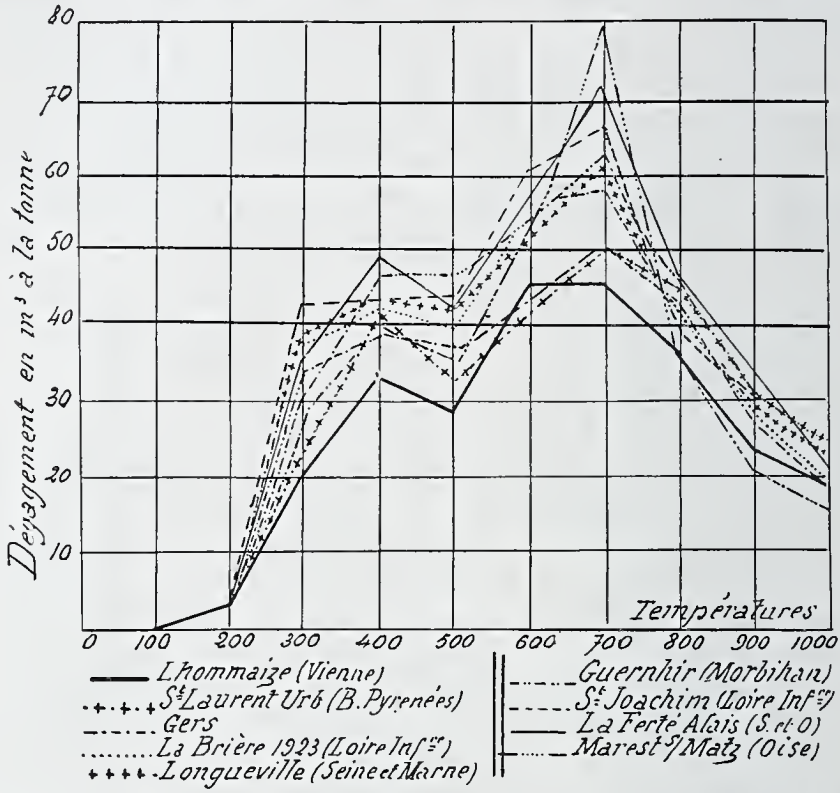


FIG. 8. LIBERATION OF GASES FROM NINE DIFFERENT PEAT SAMPLES

grass peats, or into swamp peats of plain or mountain. We have taken into account only their geographical origin.

Figure 7 relates to a peat of Ferté-Alais, Seine-et-Oise. If we compare the graph representing the total gaseous emissions with the corresponding graphs of cellulose, of lignin and of wood, one sees a lowering of the maximum of 400° characteristic of cellulose, while the maximum of 700° corresponding to lignin is exceeded.

The cellulose has almost totally disappeared, probably having been transformed into products of hydrolysis.

The more resistant lignin has likewise undergone modifications,

which are clearly indicated by the displacement of the maximum of the carbon monoxide, that passes from 500° to 600° as is clearly seen to 700°.

In Figure 8, in which are brought together the graphs of nine samples coming from different peat bogs scattered over French territory, we see their great resemblance. In all the emission of gases starts at 200°, and all include a level part or a slight maximum at 400° with a much more evident maximum at 700°.

TABLE III

PEATS

ORIGIN OF SAMPLES	VOLATILE SUB-STANCES	ASH	VOLUME OF GASES PER TON	VOLUME OF GASES PER TON, ASH DE-DUCTED	COMBUS-TIBLE GAS
		per cent	*m.*³		*per cent*
Gers	50.0	15.0	291.0	342	70.45
Saint-Joachim 1921 (Loire-Inférieure)	55.0	5.4	343.1	362	71.32
La Brière 1921 (Loire-Inférieure)	50.0	5.0	327.3	389	72.21
La Brière 1923 (Loire-Inférieure)	41.8	3.6	316.4	328	69.08
La Ferté Alais (crude) (Seine et Oise)	52.5	6.0	352.2	375	71.37
La Ferté Alais (pulverized) (Seine et Oise)	51.5	6.5	350.2	375	72.24
Marest sur Matz	52.5	13.5	304.2	352	70.44
Cinqueux	56.5	21.0	318.0	402	71.85
Longueville	56.0	13.0	322.1	370	70.37
St. Laurent (crude)	57.8	2.5	315.0	324	72.90
St. Laurent (non-fibrous)	62.5	9.8	284.2	314	72.05
St. Laurent (fibrous only)	59.5	12.0	273.3	311	72.34
Lhommaize	49.5	27.3	257.6	355	74.86
Guernhir inférieure (Finistère)	56.0	4.3	300.2	315	75.45
Guernhir supérieure (Finistère)	53.5	7.6	267.5	290	73.59
Guernhir pulverized (Finistère)	56.5	2.5	276.5	284	72.19

In our tests we have worked with peats dried beforehand at 100°. The quantitative results assembled below show that the gaseous volumes liberated up to 1,000° are rather high and comprised between 300 and 400 m³. per ton. The content in combustible gases varies from 70 to 75 per cent.

The percentages of the most abundant constituents are, in general, rather alike.

The percentage of hydrogen varies between 30 and 45 per cent, and rarely exceeds the percentages found in the gases from lignins. The

gases from peats are also characterized by greater proportion of carbonic anhydride, which is due to the presence of considerable quantities of products of the hydrolysis of cellulose.

The peats form, then, the first very homogeneous group of combustibles that we are going to see differentiated clearly from the following group, that is, the lignites.

TABLE IV

PERCENTAGE COMPOSITION OF PEAT GASES

ORIGIN OF SAMPLES	H	CH_4	CO	CO_2	C_2H_6 AND C_3H_8	C_2H_4	H_2S	N AND UNDETERMINED
Gers	36.55	7.35	24.10	26.93	0.77	1.05	0.63	2.62
Saint-Joachim 1921 (Loire-Inférieure)	43.40	4.71	20.00	27.30	1.46	0.86	0.89	1.38
La Brière 1921 (Loire-Inférieure)	46.70	4.50	18.90	26.69	0.91	0.75	0.45	1.10
La Brière 1923 (Loire-Inférieure)	38.95	9.20	16.40	25.77	2.37	1.67	0.49	5.15
La Ferté Alais (crude) (Seine et Oise)	35.17	5.10	27.40	27.50	1.15	1.11	1.44	1.13
La Ferté Alais (pulverized) (Seine et Oise)	31.55	9.35	26.50	24.46	0.85	1.04	3.15	3.30
Marest sur Matz	37.76	6.45	21.05	26.12	0.53	1.41	3.24	3.44
Cinqueux	36.97	4.10	25.05	25.07	0.83	0.95	3.95	3.08
Longueville	36.53	9.02	19.60	26.03	1.51	0.85	2.85	3.60
Saint-Laurent (crude)	37.26	10.32	24.00	21.80	0.50	0.82	0.00	5.30
St. Laurent (non-fibrous)	36.30	10.20	23.80	24.75	0.78	0.97	0.00	3.20
St. Laurent (fibrous alone)	39.81	9.85	20.83	25.55	1.00	0.85	0.00	2.11
Lhommaize	37.50	8.50	24.40	21.54	1.92	1.01	1.53	3.60
Guernhir inférieure (Finistère)	35.35	8.85	29.30	22.35	1.20	0.75	0.00	2.20
Guernhir supérieure (Finistère)	41.20	9.00	21.60	23.21	1.12	0.67	0.00	3.20
Guernhir (pulverized) (Finistère)	42.11	7.60	19.20	21.73	1.72	1.07	0.49	6.08

2. Lignites. The application of the thermic fractioning process of destructive distillation to this category of combustibles has permitted classifying them into the following two types:

a. Lignite of the Manosque-Fuveau type, in case of which a maximum freeing of gases occurs at 700°, corresponding to that of hydrogen and carbon monoxide. All the lignites of this category possess this peculiarity.

The liberation of gases begins in an appreciable degree in the region

200° to 300°, but always remains less than that given for the peats at this same temperature. It is in this zone that the emission of carbonic dioxide gas begins, which attains its maximum at 400° and then very rapidly grows less and less.

b. Lignite of the Saint-Paulet du Caisson type, characterized by a graph showing a very accentuated maximum at 800° corresponding to the most abundant liberation of hydrogen and carbon monoxide.

The graphs of lignites of this group all have this same characteristic curve. The liberation of gases does not occur in considerable

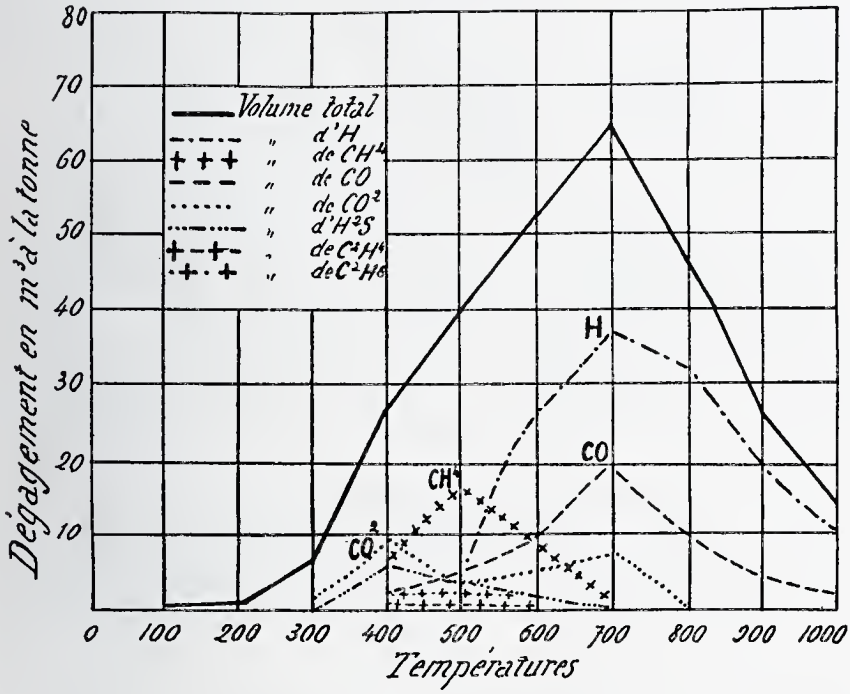


FIG. 9. LIBERATION OF GASES FROM LIGNITE OF THE MANOSQUE-FUVEAU TYPE

quantities until 300° is reached. The total gaseous volumes given off up to 1,000° by the lignites of one or the other of these groups are rather high, but the comparison of these volumes does not lead to any interesting observation, which may be attributed to the relatively small number of samples examined. The proportion of combustible gases lies between 75 and 90 per cent.

The examination of the percental compositions of gases shows that the contents of hydrogen are generally in the neighborhood of 50 per cent, and that those of carbon monoxide stay close to 20 per

cent. Hydrogen sulfide is more abundant in the lignites of the second group.

3. Coals. Numerous samples of coal were examined. Like the lignites, they fall into two types differentiated by the temperature at which the liberation of gases is the most abundant. The graph in Figure 11, of a Bruay coal (Fig. 11) is characteristic of the first type. The liberation of gases that is already considerable in the zone from 400° to 500° exceeds 20 cubic meters to the ton at this last tem-

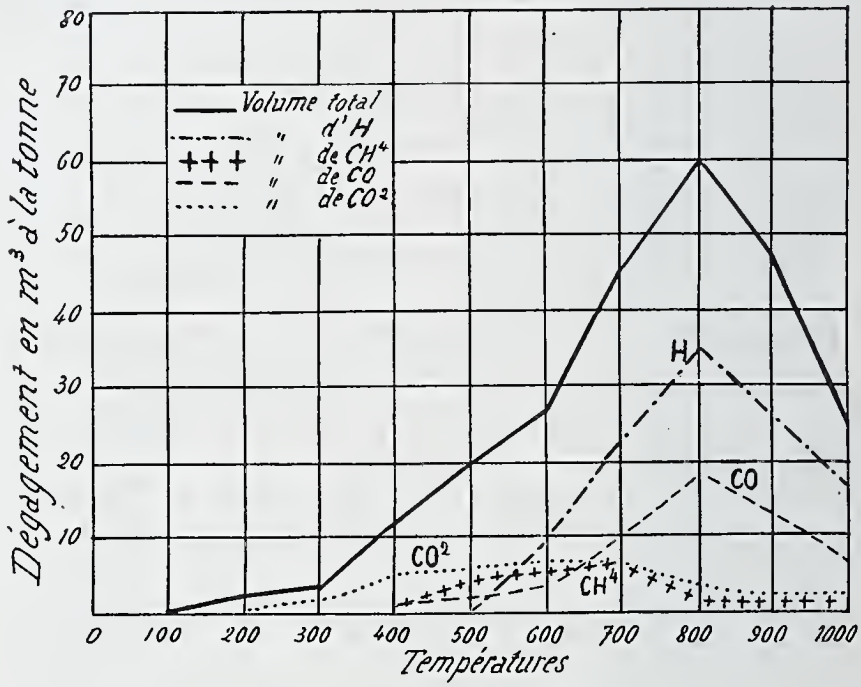


FIG. 10. LIBERATION OF GASES FROM LIGNITE OF THE SAINT PAULET DU CAISSON TYPE

perature. The maximum is reached at 700°. As far as the constituents are concerned, hydrogen has its maximum at 800°, methane at 600°, and carbon monoxide at 700°.

The second type, for which a coal from the Alais basin can serve us as an example, is characterized especially by the shifting towards 800°, of the maximum production of gas (Fig. 12), and an obvious decrease of the quantity of gas given off at 400° to 500°, a quantity which is almost always lower than 20 cubic meters.

Up to 1,000°, the total volume of the gases extracted per ton is of

the same order of magnitude for the two kinds of coal and the yield for the greater number of samples examined is between 290 and 340 m^3.

An appreciable difference exists between the contents in hydrogen, which for the first type vary from 60 to 75 per cent, and for the second are above this last number sometimes reaching 78 per cent. The proportions of methane are approximately constant (17 to 20

TABLE V

LIGNITES

ORIGIN OF SAMPLES	VOLATILE SUB-STANCES	ASH	VOLUME OF GASES PER TON	VOLUME OF GASES PER TON, ASH DEDUCTED	COMBUS-TIBLE GAS
Maximum at 700°					
		per cent	*m.*³		*per cent*
Portuguese lignite	55.63	6.48	347.09	371	
Roumanian lignite	54.57	12.19	307.99	350	
Chilean lignite	42.00	2.54	314.39	322	
Yugoslavic lignite (surface)	72.30	1.58	240.50	244	89.73
Yugoslavic lignite (fibrous)	66.22	10.30	322.52	359	75.70
Voglans lignite	31.0	10.40	181.59	204	74.86
Manosque-Fuveau lignite	39.0	15.50	278.49	329	89.24
Maximum at 800°					
Rich Manosque lignite	32.70	4.02	159.74	166	84.36
Lean Manosque lignite	31.50	14.20	254.09	295	85.64
St. Paulet du Caisson lignite	50.03	13.71	242.07	275	88.88
Monferrat lignite	38.00	13.40	228.77	264	87.49
Italian lignite	43.50	28.84	278.37	491	89.68

per cent). On the contrary, the content in carbon monoxide was from 5 to 14 per cent.

4. Anthracites. The anthracites are generally used directly as fuels, and their carbonization has been rarely considered; hence our knowledge on this subject has up to this time been rather limited. Our researches allowed us to make evident a few interesting properties of this kind of combustible.

It is generally agreed that anthracite from Wales can be considered as the representative type of this kind of fossil coal. The graph of the destructive distillation of such a product is the very picture of its most characteristic properties (Fig. 13).

The emission of gases is brought about only at a relatively high temperature, which explains the difficulty of ignition. On the other hand, the chief constituent of the volatile substances being hydrogen, and the production of coal tar being almost nil, the combustion takes place with a very dim and very hot flame.

The most striking fact is the verification of a very abundant emission of gases for a coal of so low a content in volatile substances and of the same order of magnitude as that which would be produced by the carbonization of a rich coking coal. For anthracite from

TABLE VI

PERCENTAL COMPOSITION OF GASES OF LIGNITES

ORIGIN OF THE SAMPLES	H	CH_4	CO	CO_2	C_2H_6 AND C_3H_8	C_2H_4	H_2S	N AND UNDETERMINED
Maximum at 700°								
Lignite from Yugoslavia (surface)	49.57	14.70	22.80	8.88	1.24	1.39	0.23	1.19
Lignite from Yugoslavia (fibrous)	43.13	8.62	21.45	21.40	0.79	0.83	0.85	2.90
Lignite from Voglans	47.00	3.15	23.40	21.60	0.65	0.25	0.41	3.54
Manosque-Fuveau Lignite	49.40	10.45	22.05	10.35	1.85	0.99	4.50	0.41
Maximum at 800°								
Rich Manosque Lignite	44.80	10.61	16.36	12.70	2.50	1.00	10.37	1.66
Lean Manosque Lignite	47.60	11.61	20.30	10.95	2.33	0.86	6.18	0.17
St. Paulet du Caisson Lignite	47.15	7.99	23.80	12.38	1.14	0.75	6.66	0.13
Monferrat Lignite	54.85	6.49	22.18	10.17	0.43	0.36		0.05

Wales the volume of gas collected up to 1,000° was 278 m^3. to the ton containing more than 90 per cent of hydrogen.

The name of anthracitic coal is applied sometimes to certain combustibles whose content in volatile substances is from 8 to 10 per cent, which behave, however, when used in gas producers or in furnaces burning coal dust, like real anthracites with 4 to 5 per cent of volatile substances. This anomaly is explained by the study of the gaseous products of their carbonization.

Such a combustible coming from the Mines de Saint-Martin of Valgalgues, Gard, gave the graph of Figure 3 which shows the close resemblance of this coal to the anthracite from Wales, and this explains what causes it to be considered as a genuine anthracite.

In this type of combustible the freeing of gases does not begin until about 600°. The maximum freeing of gases is obtained at 800°, and the principal constituent is again hydrogen. The production of coal tar is likewise very slight, scarcely noticeable in our tests of certain samples.

The numerical results given in Table VII are very interesting.

It is found that for these combustibles with a low content in volatile substances, the quantity of the gas emitted in the course of the thermic fractioning is of the same order of magnitude as that

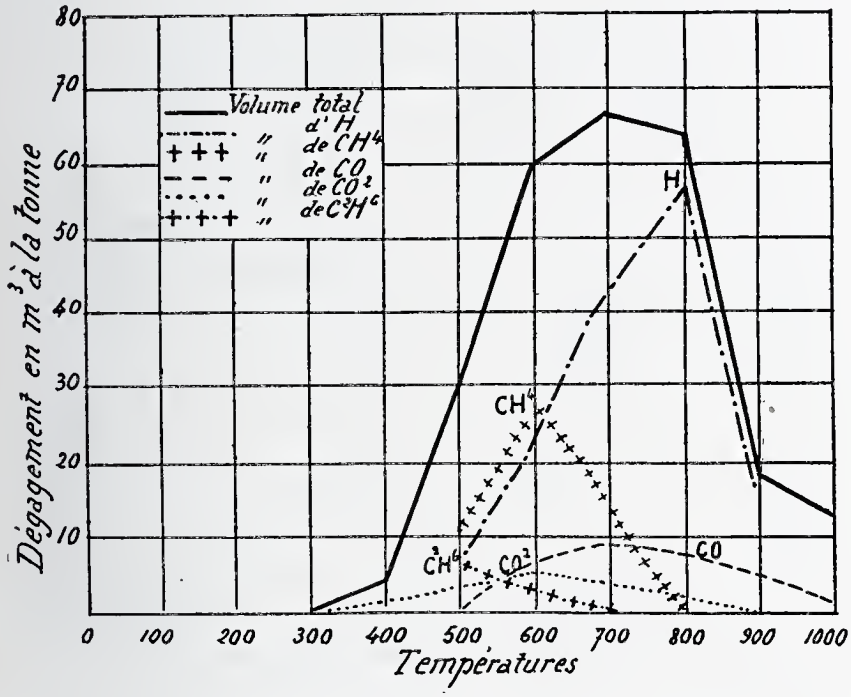


FIG. 11. LIBERATION OF GASES FROM BRUAY COAL

given by the coals which are the richest in volatile substances. This unexpected fact is so much the more interesting as the total gaseous mixture contains a proportion of hydrogen very much above that of coal gases, a proportion almost always above 80 per cent and sometimes exceeding 85 per cent. It reaches, as we have said above, 90 per cent, if we consider only the most abundant part of the gases freed between 700° and 1,000°. In case of anthracite from Wales, the gas given off between 900° and 1,000° is pure hydrogen and does not give any trace of carbonic anhydride in its eudiometric combustion.

This richness in hydrogen of anthracite gases can be of real interest in the preparation of ammonia, especially as the anthracites having been subjected to this carbonization, most often preserve their appearance, their mechanical properties, and remain the preferred combustible for certain uses.

The existence of a new group of combustibles was revealed to me by the examination of different anthracites from the region of the French Alps. These anthracites are, in fact, of a very special kind,

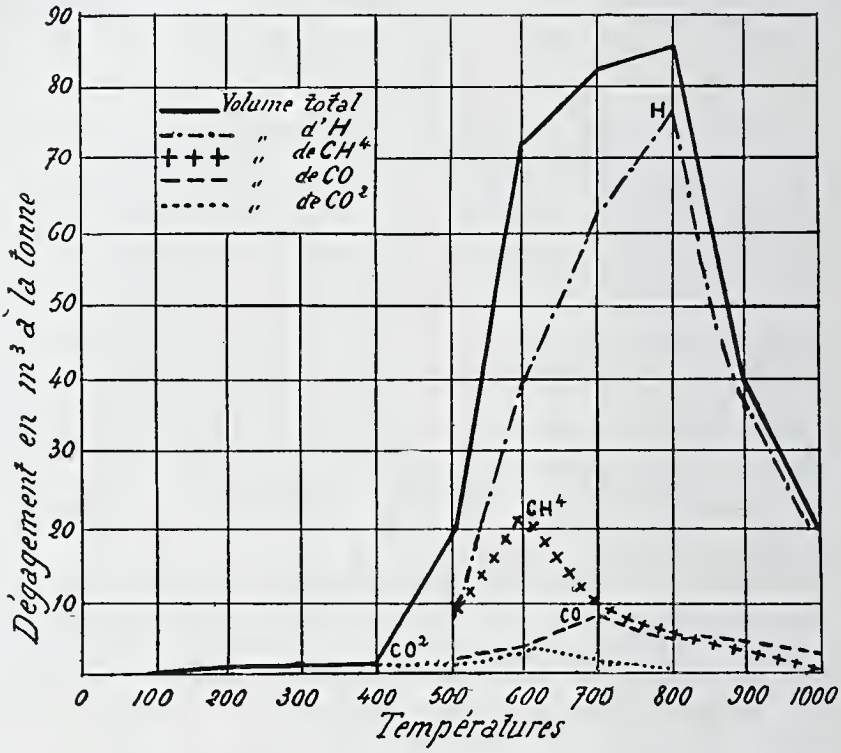


FIG. 12. LIBERATION OF GASES FROM COAL FROM THE ALAIS BASINS

as the graph below of an anthracite from the Mure (1923) allows us to verify (Fig. 14).

Here the freeing of gases takes place only to an appreciable degree at 700°, and the maximum is at 900°. Almost the sole constituent is hydrogen. Another anthracite coming from the mines of Etarpey, near Saint-Michel de Maurienne, Savoy, shows an abundant emission of gases between 700 and 800° without showing any maximum up to 1,000°. Here again, the principal constituent is hydrogen.

The anthracites of Bourg d'Oisans and of a few mines of Savoy and of Isere present the same peculiarity.

We thought that it was a question of anthracites or of coals that had undergone in the course of different geological periods, under the probable simultaneous influence of pressure and temperature, a sort of natural coking. According to M. Dagallier, a mining engineer, (*Chaleur et Industrie*, No. 40, p. 87, August, 1923), the beds formed by these coals are most often folded and double-folded; it seems that in all the districts that contain them, the coal of the initial beds

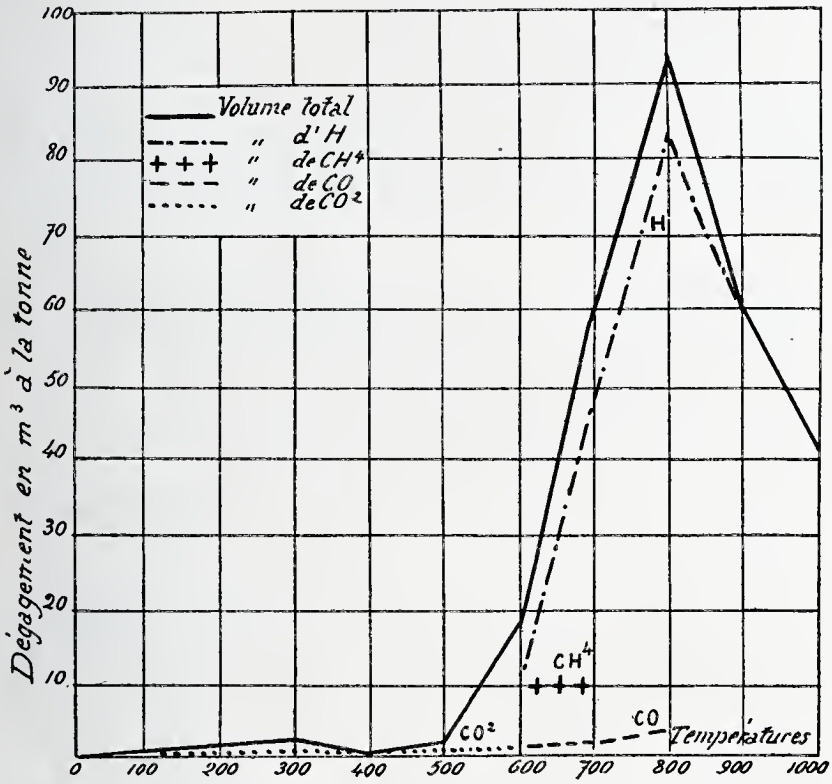


FIG. 13. LIBERATION OF GASES FROM ANTHRACITE FROM WALES

having become plastic, has frequently left its original bed and run through all the fissures and into all the interstices resulting from the dislocation. This plasticity of the coal has, perhaps, been caused by the influence of great pressure and also of high temperatures. This expert opinion agrees with the hypothesis of a natural coking that had seemed logical to us to adopt.

Other samples of combustibles which were given to us by M. Waty, Ingenieur aux Charbonnages du Dong-Trieu, Tonkin, arranged them-

selves in this category, which permitted us to make comparisons between combustibles coming from beds very far distant from each other, as we have already done with anthracites from the Alais region

TABLE VII

ORIGIN OF THE SAMPLES	H	CH_4	C_2H_6 AND C_3H_8	C_2H_4	CO	CO_2	N AND UNDETERMINED	VOLS. FREED AT 1000°	COAL TARS
	per cent	*per cent*	*per cent*						*per cent*
Wales	90.15	6.00			2.16	0.35	3.72	278.23	
Alais, Gard:									
Sample I	83.31	9.11	0.08	0.03	3.32	3.22	0.86	316.46	0.15
Sample II	87.32	8.54	0.08	0.08	2.71	0.34	0.85	295.14	0.10
Sample III	83.95	9.77	0.07	0.02	2.62	1.40	2.12	302.71	0.03

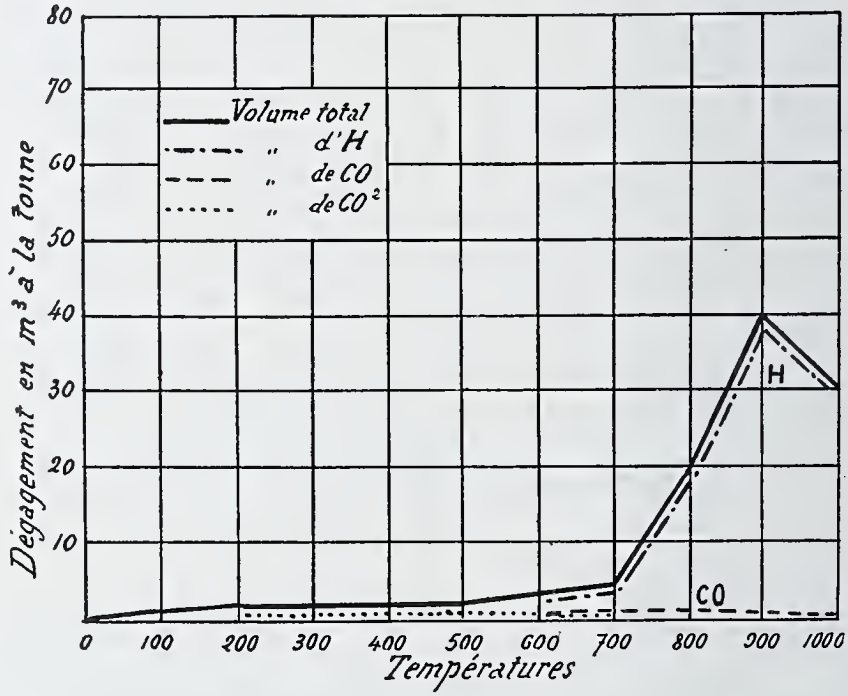


FIG. 14. LIBERATION OF GASES FROM ANTHRACITE FROM THE MURE (1923)

and from Wales. The graphs of the Tomkin coals which are brought together in Figures 16 and 17 make their close relationship stand out, and their ensemble can form two sub-graphs with well determined characteristics.

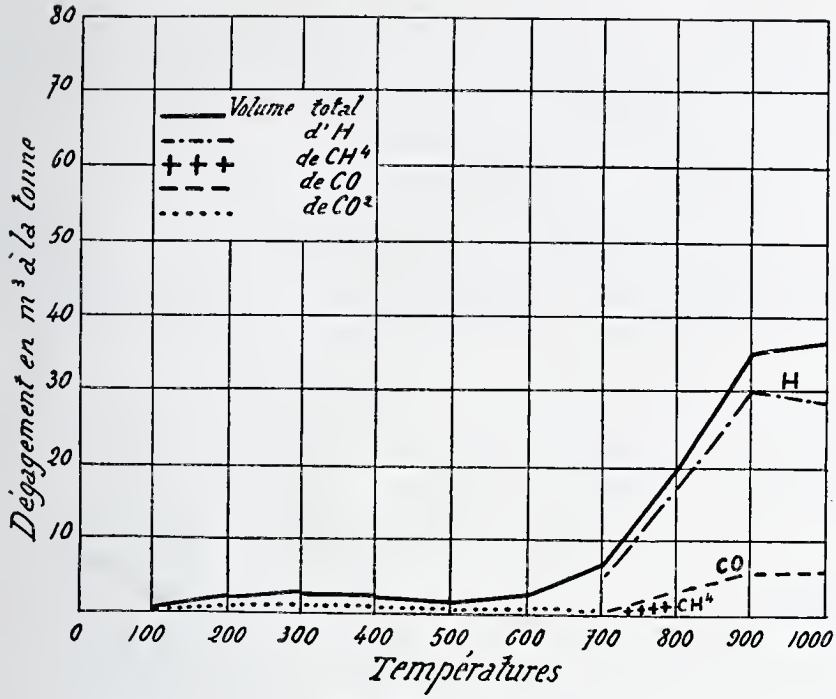


FIG. 15. LIBERATION OF GASES FROM ANTHRACITE FROM ETARPEY

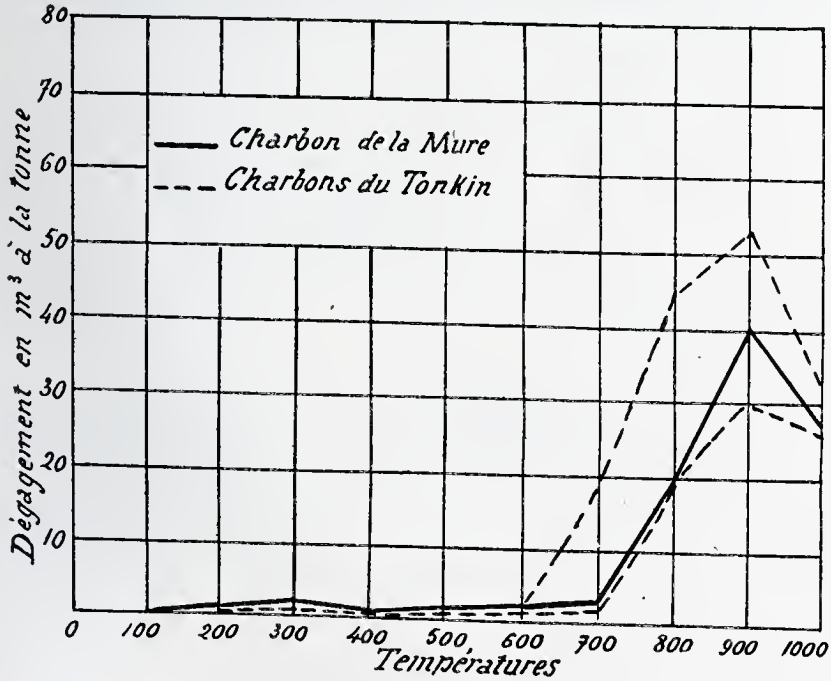


FIG. 16. LIBERATION OF GASES FROM COAL FROM LA MURE AND COALS FROM TONKIN

In the first one (Fig. 16), the graphs present by way of analogy a distinct maximum at 900°, with rather different gaseous volumes, but very much lower than those given by real anthracites having the same content in volatile substances.

The beginning of the liberation of gases does not occur to an appreciable degree until from 600° to 700° in the second sub-group (Fig. 17), with real emission only from 700° and up, and no distinct maximum before 1,000°. The opinion of M. Waty, in the note which

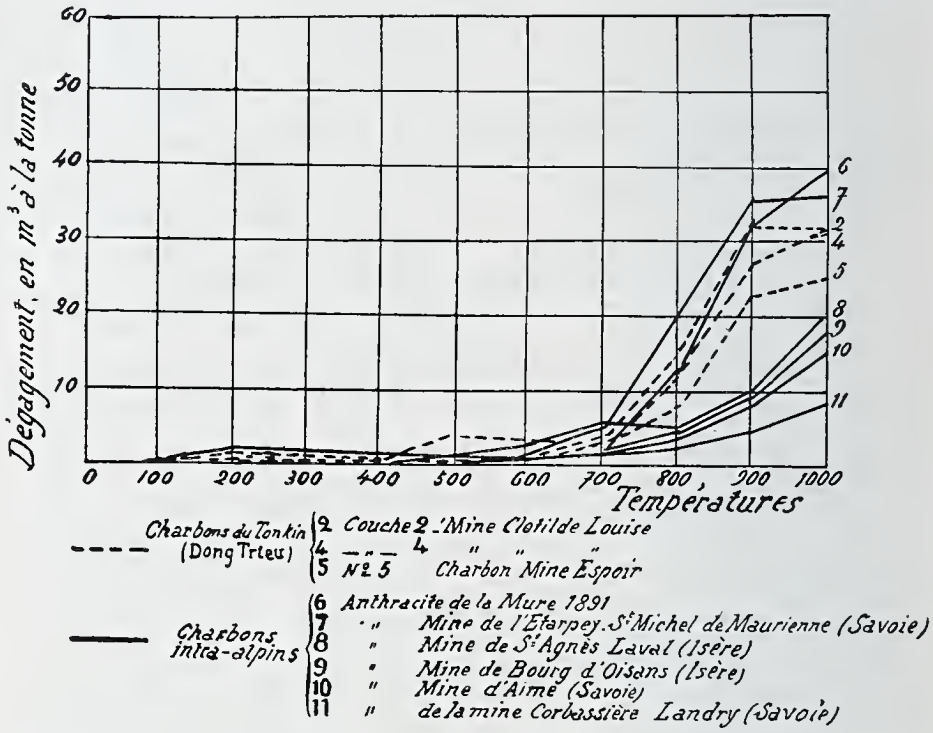


FIG. 17. LIBERATION OF GASES FROM COALS FROM TONKIN AND FROM INTER-ALPINE COALS

he sent concerning the geological location and the description of the different strata, is that it is a question of the products of transformation of a coal of an ancient formation that has probably been acted upon by fire, compressed, and laminated under the influence of geological cataclysms which caused upheavals in the Dong-Trieu region; all this is in accord with a hypothesis of coking that we have adopted for the inter-Alpine anthracites.

You may ask, what are the volatile substances, which added to the

gases, give the proportion that reaches, for example, more than 10 per cent in case of anthracites from the Mure and is never below 3 per cent? The weight of the total volume of gases freed, which are principally composed of hydrogen, is, in fact, much below the weight of the volatile substances resulting from the customary calculations. This fact is solely due to the presence, in all these samples of anthracite, to a quantity of included water (eau d'interposition) which is only slightly eliminated at 100°, and which, in the majority of cases, is given off at a higher temperature and causes sometimes an excessively violent decrepitation.

We propose to give to the combustibles of the two sub-groups that we have just studied in the last place, the name of pyro-anthracites, a name, it seems to us, that recalls very well their properties and their very probable geological formation.

The studies, of which we have recapitulated the chief results, result from the examination of more than 400 samples of combustibles or of carbonizable substances. The conclusion that can be drawn from them have thus an indisputable value from the point of view of their generality. That is why we feel warranted to terminate this paper by proposing a more complete and more precise classification of fossil combustibles, based upon the more perfect knowledge of the liberation and the nature of the gaseous products of carbonization.

CLASSIFICATION OF FOSSIL COMBUSTIBLES

1. The peats, a very homogeneous group, of which we have already given the characteristics.

2. The lignites forming two sub-groups:

a. The coal lignites having a maximum liberation of gases at 700° as the coals, which could be considered as capable of evolving towards this type of coal.

b. The anthracitic lignites with a maximum liberation of gases at 800°, whose graphs are already very close to those of anthracites.

3. The coals forming likewise two sub-groups:

a. The coals properly speaking with a distinct maximum at 700° or verging toward 600°, whose gaseous emissions in the region of 400° to 500° is above 20 m^3.; the content in hydrogen of the total gaseous mixture varying from 60 to 75 per cent, and the proportion of coal tar formed in the course of the tests being generally above 4 per cent.

b. The anthracitic coals in the region of 700° to 800°, or with a

tendency to a maximum at about 800°, but whose gaseous emission at the region 400° to 500° does not much exceed 20 m^3. Content in hydrogen of the gaseous mixtures: 75 to 78 per cent; the proportion of coal tar formed is below 4 per cent.

4. The anthracites having a very marked maximum of emission at 800°, with a liberation of gases in the region of 400° to 500° below 10 m^3., the content in hydrogen of the gaseous mixtures varying from 78 to 85 per cent and even beyond. Proportion of coal tar: nil or very slight.

5. The pyro-anthracites, which, from the samples studied, are classified into two kinds:

a. The pyro-anthracites with a maximum at 900°. An appreciable liberation of gases at the zone 600° to 700°; gases constituted of hydrogen or carbon monoxide and carbonic acid without hydrocarbons or slight traces of hydrocarbons;

b. Pyro-anthracites without a distinct maximum below 1,000°. Liberation of gases not becoming important until about 700°. Gas constituted by hydrogen, carbon monoxide, and carbonic anhydride, and as before, absence of, or very small traces of hydrocarbons.

SOME RECENT DEVELOPMENTS ON THE CONSTITUTION OF COAL[1]

By Reinhardt Thiessen[2]

United States Bureau of Mines, Pittsburgh, Pennsylvania

I. The Banded Constituents of Coal: Earlier Knowledge of Coal

Goeppert,[3] with the background of the works of Beroldingen, De Luc, Playfair, Williams, Darwin, Parkinson, McCulloch, and others; also with his intimate knowledge of geology, botany, paleobotany, and the use of the microscope gave us for the first time a definite knowledge of the origin and composition of coal and of the kinds of plants that contributed and what kind of coal they formed.

From Goeppert in 1846 to Guembel[4] in 1883, we pass over a considerable period during which no great results were obtained. Guembel gave as precise a summary as to what coal is as could be given at that time when he says that true coals, aside from a small amount of earthy matter, are composed of combustible substances in which the texture of land plants, to which they owe their origin, is preserved through and through in a recognizable form. All possible plant structure and tissues, such as woody tissues, bark tissues and fibers, parenchymatous tissues, epidermal tissues, cuticles, spores, pollen grains, algal-like objects, resins and other minor substances are recognized. In the coal all is bound together by a homogeneous huminlike mass which Guembel called "carbohumin," into a more or less homogeneous appearing whole. Many of the plant constituents have lost completely their form and consistency and have changed into a huminlike substance, embedded and absorbed by remaining plant fragments.

Guembel also made distinctions in the bright and the dull portions

[1] Published by permission of the Director, U. S. Bureau of Mines. (Not subject to copyright.)

[2] Research chemist and microscopist, Pittsburgh Experiment Station.

[3] Goeppert, H. R., Preisschrift über Steinkohlen. *Harlem Nat. Verhand. Monatsch.*, *4*, 1–298 (1846).

[4] Guembel, C. W. von., Beitrage zur Kenntnisse der Textur verhaltnisse der Mineralkohlen. *Sitzb. d. Math. Phys. Classe K. B. Akad. Wiss.*, *13*, 111–216 (1883).

of coal. During the same time Muck,[5] a teacher at the Mining School at Bochum, worked out his "Chemie der Steinkohle," of which a second edition appeared in 1891. In this work the first description and definition of the components known as "Glanzkohle," "Mattkohle," and "Streifenkohle" are given as clearly as they ever have been given. The striped appearance of coal had given Schondorff the notion of calling them "Streifenkohlen." Although Schondorff's term applied only to the Saar Mattkohle, Muck applies it to all coals and from this we have the general term striped or banded coals.

No further advances of note were made until we reach the twentieth century with Potonie[6] as the outstanding figure. He made further valuable contributions to the knowledge of coal in general, and is the first in the endeavor to explain the layering of coal. He gathers all combustible organic materials under the term "Kaustobioliths." These are subdivided into three great groups: humus coals, sapropeliths, and liptobioliths.

According to Potonie, humus coal is derived chiefly from land plants, hydrophytic plants whose upper parts live essentially in air, and a few related aquatic plants, and in a similar manner as we know peat to be formed today.

Sapropeliths were formed in stagnant waters. The contributants were aquatic organisms, of which microörganisms and chiefly such as form planktons constituted the most important part. Cannel coal is a type of sapropel.

Liptobioliths are the resistant residues accumulated during more complete decomposition of many plants. They consist for the most part of spores, pollens, resins, and waxes.

According to Potonie's views, an ordinary striped or banded coal is the result of the foregoing three conditions in a struggle for dominance. During the formation of the deposit at various times one or the other of these conditions prevailed. If the area was under the ordinary humic conditions, humus or glanzcoal was formed; if extraordinarily wet, so that the area was flooded with water, sapropel, or dull or matt coal was formed; again, when the area was very dry, all but the most resistant matter was decomposed and a liptobiolith was

[5] Muck, Friederich, *Die Chemie der Steinkohle*, 1st ed., 1881; 2d ed., 1891.

[6] Potonie, H., Die Enstekung der Steinkohle und der Kaustobiolithe überhaupt (1912); Klassification and Terminologie der rezenten brennbaren Biolithe und ihrer lagerslätten. *Abhandl d. Kl. Preuss, Geol. Landesanst. u. Bergad.* (1906).

formed. Most often only the first two were involved. These conditions in many cases alternated frequently in rapid succession and the result was an ordinary striped or banded coal, illustrated in Figure 1. The black bands are humus or glanz coal, those inclusions marked *a* are charcoal; all of the remainder is matt or dull coal. Beyond this description nothing is revealed of the structure of any

FIG. 1. STREIFENKOHLE FROM THE SAAR DISTRICT, ST. INGEBERT MINE, PHALZ

The black stripes are Glanzkohle or Humuskohle; the lighter parts are Mattkohle; *a* is Faserkohle. (Natural size.) After H. Potonie (Fig. 29), Die Entrtehung der Steinkohle, 1910.

of the bands. As far as can be determined, Potonie's theory largely holds in Germany today.

DEVELOPMENT OF AMERICAN NOMENCLATURE

These few brief summaries give us the essentials of the knowledge of the origin, composition, and structure of coal at the time when the United States Geological Survey, through the endeavors of David White, took up the research on coal. The first objectives sought were to explain the meaning of the layering or banding which up to then had not been explained and had been responsible for various theories;

and secondly, to discover the nature and origin of the pitch-like or jet-black inclusions in coal as well as the structure and origin in general.

The studies were begun on the lignites and from them passed progressively into the higher rank coals. In the investigation of the

FIG. 2. PEAT FROM A WISCONSIN WOODED PEAT SWAMP

Note the fragments of woody peat embedded in the attritus; these are the analogy of anthraxylon in coal. (Natural size.)

lignites it was soon found that the pitchy, jet-like, bright layers and inclusions were invariably derived from pieces of wood—that is, they represent fragments of more or less rotted wood now transformed into coal. These pieces ranged in size from small slivers to chunks of wood or parts of tree trunks, and were in every way analogous to peat-wood in peat, which was studied simultaneously—that is, every constituent found in peat is also found in all the ordinary coals

through the whole series from brown coals to anthracite, but in different degrees of coalification. Figure 2 represents a lump of peat from a forested or wooded swamp. In it we have a ground mass or matrix in the state of a muck when wet, consisting of a macerated mass of semi-decayed plant debris derived from all kinds of plant substances—in other words, an attritus. In it are embedded fragments of half-rotted wood of all sizes. If in a lump of peat as shown

FIG. 3. FRAGMENTS OF WOODY PEAT REMOVED FROM A LUMP OF WISCONSIN PEAT, SIMILAR TO THE LUMP SHOWN IN FIGURE 2

These chips of woody peat are the analogy of anthraxylon in coal. (Natural size.)

in Figure 2 these fragments are separated from the attritus, their true nature is revealed as is shown in Figure 3.

When the same studies were carried progressively into the paleozoic coals,[7] it was found there also that the bright, jet-like bands were

[7] White, David, and Thiessen, Reinhardt, The Origin of Coal. U. S. Bureau of Mines Bull. 38, 1913, 390 pp.; Thiessen, Reinhardt, Structure in Paleozoic Bituminous Coals. U. S. Bureau of Mines Bull. 117, 1920, 296 pp.

of a similar origin; also, that there were no essential differences in origin and composition of all the kinds and grades of the ordinary banded coals from the lignites to the high-rank bituminous coals.

The essential points covering the structure and composition of coal as they now have been worked out may be briefly repeated with profit: All ordinary coals at a casual observation are seen to be banded or layered. (Fig. 4.) When examined more closely they are seen to be composed of many layers or seams differing from one another in color, texture, fracture, hardness, ability to absorb or

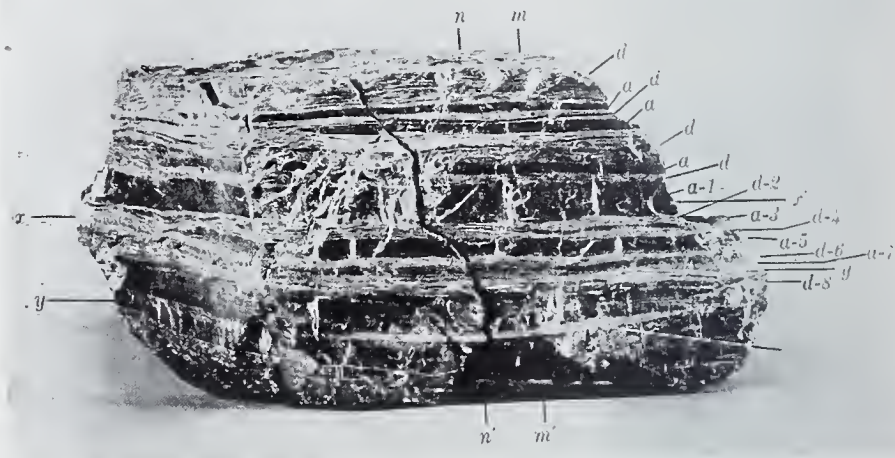


FIG. 4. BLOCK OF ILLINOIS COAL FROM NO. 6 BED

The black bands *a* represent anthraxylon; the grayish bands *d* represent layers of dull coal or attritus, including very thin strips of anthraxylon. The area blocked out by the lines x–x^1 and y–y^1 intersecting n–n^1 and m–m^1 is the area shown in Figure 4 enlarged 10 times. From Compilation and Composition of Bituminous Coals, *Jour. of Geology*, vol. 38, 1920, 38, pp. 185–209.

reflect light, and differing greatly in thickness and length, some relatively bright, others dull in appearance. (Figs. 4 and 5.)

These bright and jet-like bands had been named "bright coal" after the European terminology. The duller portion was termed "dull coal," as it was believed that it was of the same nature as those components termed dull coal or Mattkohle of the Europeans.

It was found that the bright bands, irrespective of what coal or of what dimension, invariably revealed plant structure mostly well enough preserved to be easily recognizable, but often poorly preserved and recognized with difficulty; invariably they were analogous to

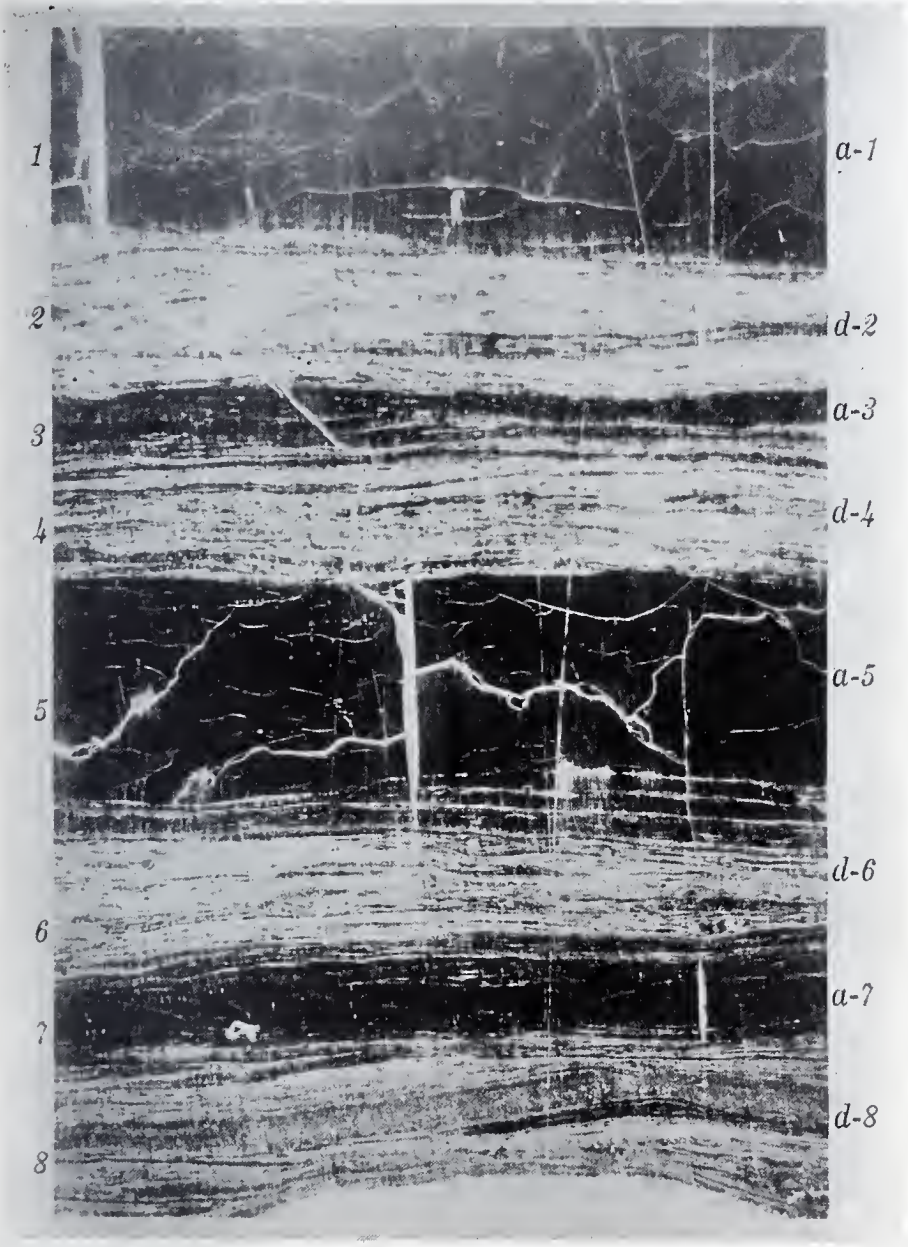


FIG. 5. THE AREA BLOCKED OUT BY THE LINES x–x^1, y–y^1, INTERSECTING WITH n–n^1 AND m–m^1 IN FIGURE 4 AND ENLARGED 10 TIMES

After Thiessen in *Journal of Geology* (*28*, 1920, p. 209). The bands *a–1*, *d–2*, *a–3*, *d–4*, *a–5*, *d–6*, *a–7*, and *d–8* represent alternate layers of anthraxylon and dull coal, or attritus including thin strips of anthraxylon.

FIG. 6. THIN CROSS-SECTION OF GERMAN EARTHY-BROWN COAL FROM THE HALLE DISTRICT, SHOWING A BAND OF WOODY-BROWN COAL, ANTHRAXYLON ABOVE AND ATTRITUS BELOW. (×200)

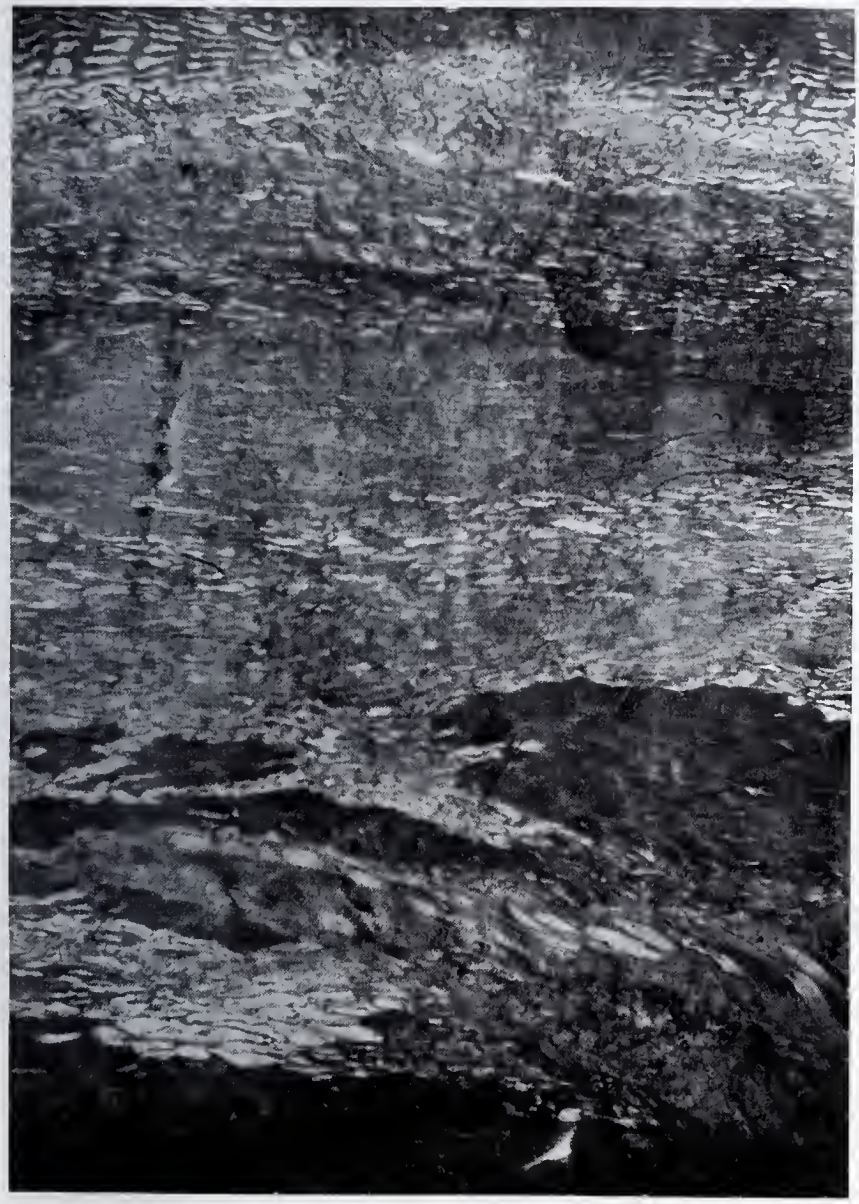


Fig. 7. Thin Cross-section of Anthraxylon of a High-Rank Lignite from the Ganthar Mine, Roundup, Montana, Showing all Structure Fairly Well Preserved. (×20)

FIG. 8. THIN CROSS-SECTION OF ANTHRAXYLON OF A BITUMINOUS COAL FROM THE PITTSBURGH BED. CELL STRUCTURE WELL PRESERVED, WITH RESIN CONTENT. (×20)

fragments of woody tissue in peat. (Figs. 6, 7, 8, and 9.) In order to designate definitely such constituents by means of a descriptive term, they were called "anthraxylon;" from anthrax, coal, and xylon, wood. Therefore, whenever and wherever the term anthraxylon is used it designates definitely certain definite components of any coal, whether brown coal, lignite, sub-bituminous, bituminous or

Fig. 9. Thin Cross-section of Coal from No. 6 Bed, Illinois, Showing Several Anthraxylon Bands in Which the Cell Structure is Poorly Preserved. (×200)

anthracite, derived from the woody tissues of plants, such as of the stems, twigs, roots, including lignified cortex or periderm.

The duller portion in the coal, or that part of the coal in which the bright bands or anthraxylon units are embedded, and which forms the ground mass consists of a granular mass composed of all kinds of degradation plant matter. It is analogous to the black muck in peat. As it is composed of a finely macerated plant mass, or attrition matter, it was termed "attritus," to give it a definite descriptive term.

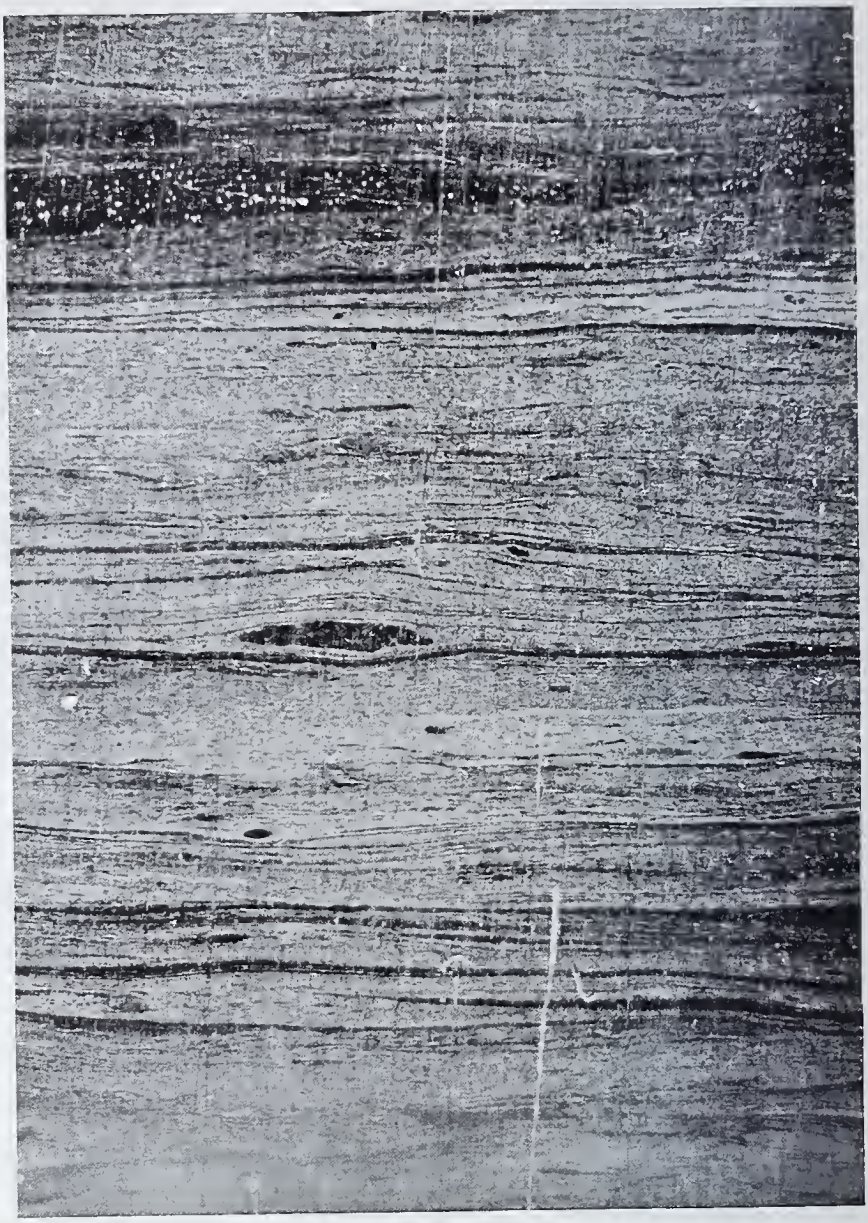


Fig. 10. Part of Polished Surface of Pittsburgh Coal, Bureau of Mines Experimental Mine, Consisting of Attritus Interlayered with a Number of Thin Anthraxylon Sheets, Prepared from a Coal Similar to That Shown in Figure 19. (×10)

The attritus is the general residue left from all possible kinds of plants, plant products, and plant organs, exposed for many years to the ravages of all kinds of microörganisms and meteorological conditions before it was subjected to further coal-forming processes.

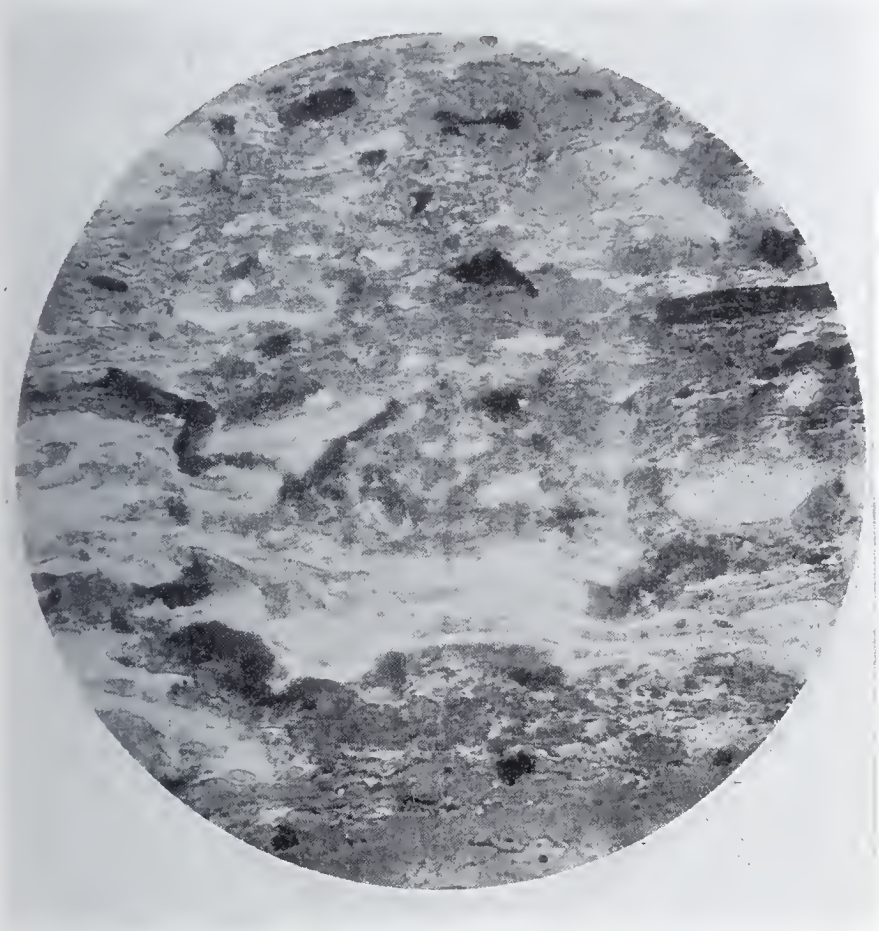


Fig. 11. Thin Cross-section of Attritus of a Peat Briquette Made from Peat Similar to That Shown in Figure 2

Note the spores, pollens, and opaque matter distributed among the general humic degradation matter. (× 1000)

It consists of the most and the more resistant plant matter, and forms a very heterogeneous mass; in fact, it is so varied that it defies a general description. Under a lower magnification the attritus appears as a striated to smooth granular mass. (Fig. 10.) At a

Fig. 12. Thin Cross-section of Attritus of a High-rank Lignite from the Ganthar Mine, Roundup, Montana

Note the thin strip of anthraxylon in the lower part, also spores, resins, opaque matter mixed with the humic degradation matter. (×200)

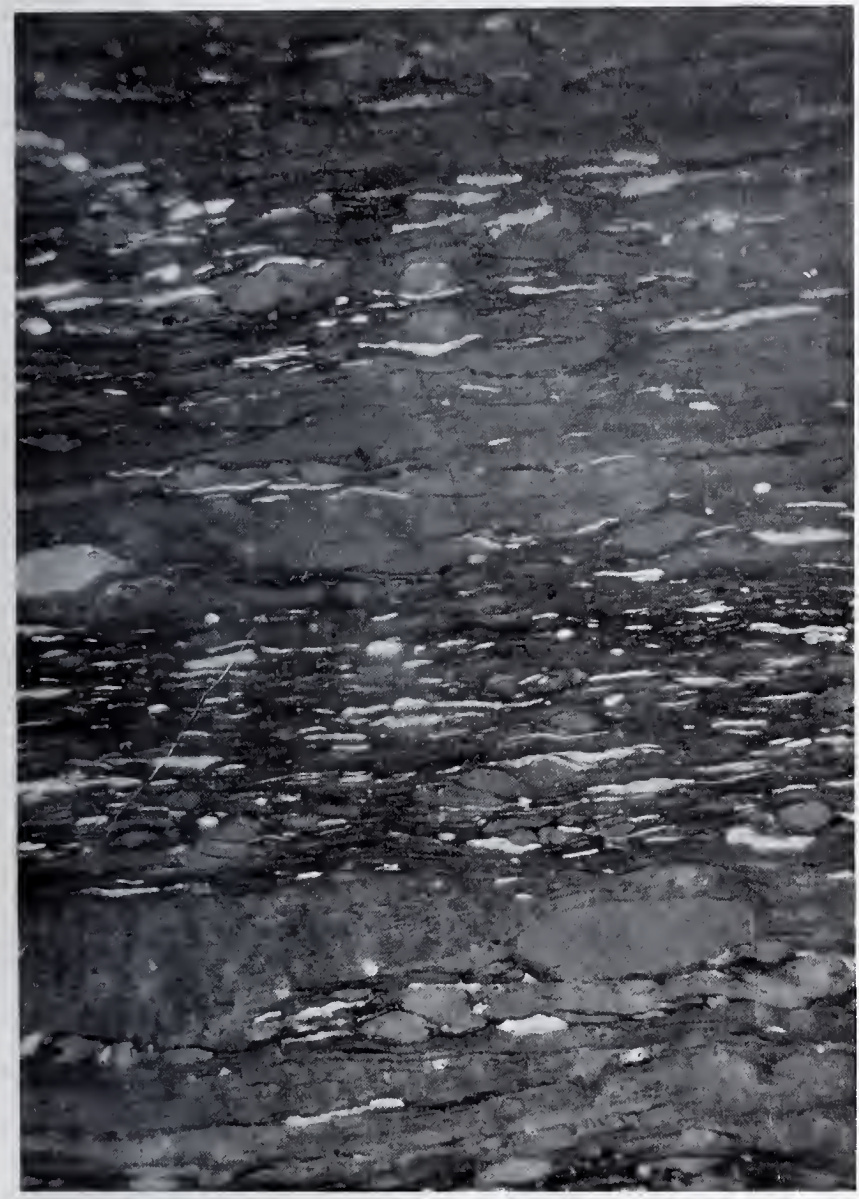


Fig. 13. Thin Cross-section of Attritus of Coal from the Brookville Bed, Showing Spores, Resinous Particles, Opaque Matter and a General Humic Degradation Matter, Some of Which Reveals Plant Structure. (×200)

FIG. 14. THIN CROSS-SECTION OF ATTRITUS OF PITTSBURGH COAL, SHOWING A NUMBER OF THIN ANTHRAXYLON BANDS IN THE ATTRITUS

Note the opaque matter, shown in black; also the finer sizes of the humic matter in general. (×200.)

higher magnification, greater than 100 diameters, it is resolved into a number of constituents. (Figs. 11, 12, 13, 14, and 15.) The more important of these are minute anthraxylon units, woody degradation matter, very finely divided humic degradation matter such as of

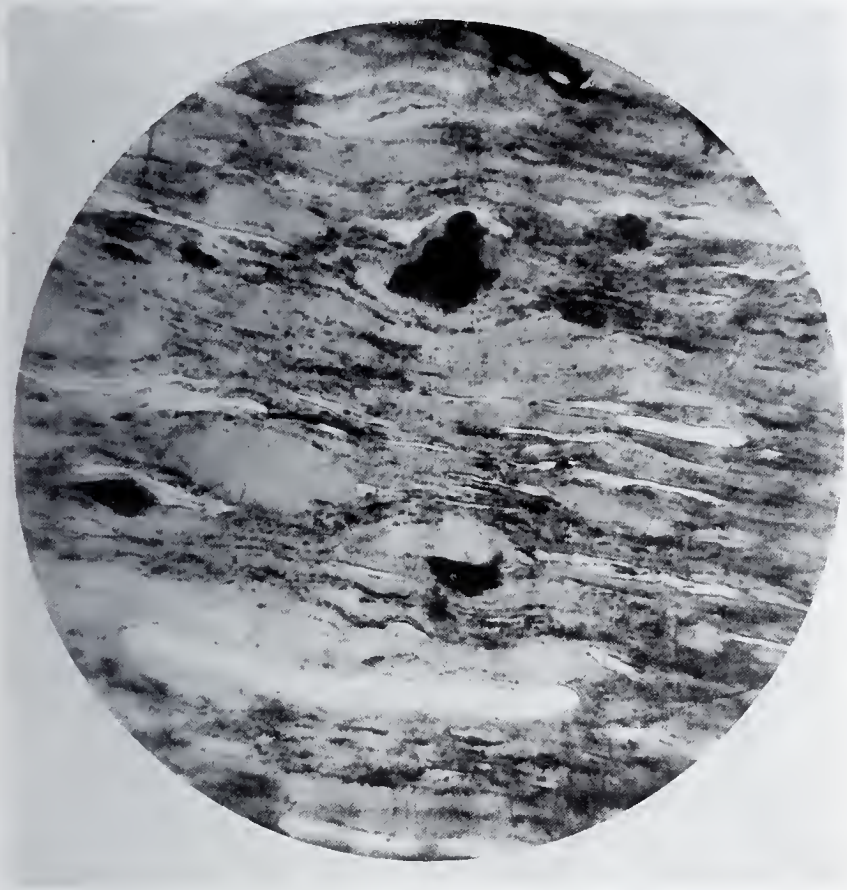


FIG. 15. THIN CROSS-SECTION OF ATTRITUS OF UPPER FREEPORT COAL, OAKMONT MINE, AT A HIGHER MAGNIFICATION, SHOWING THE CONSTITUENTS, SUCH AS SPORES, RESINOUS PARTICLES, OPAQUE MATTER, AND HUMIC DEGRADATION MATTER IN BETTER DETAIL. (×1000)

bark, cortex, leaf parenchyma, herbaceous parenchyma and pith; further whole or parts of spores, pollens, cuticles, resins, waxy matter, and rodlets, and always a greatly varying amount of more highly carbonized or opaque matter. These constituents may form the attritus in all possible proportions and lend various characteristic

qualities and appearances to it according to the prominence of the one or the other of these constituents.[8]

The compilation of a coal, or the relative proportions of these two components, anthraxylon and attritus, is a very important factor in

FIG. 16. CANNEL COAL FROM THE TOP OF THE UPPER FREEPORT BED, OAKMONT MINE, CONSISTING ENTIRELY OF ATTRITUS. (NATURAL SIZE)

the nature of a coal. It sometimes happens that a certain layer of a coal, as is the case in the uppermost part of the thick Freeport

[8] Thiessen, Reinhardt, Compilation and Composition of Bituminous Coals. *Jour. of Geol.*, *38*, 185–209 (1920); Structure in Paleozoic Bituminous Coals. U. S. Bureau of Mines Bull. 117, 1920, 296 pp.

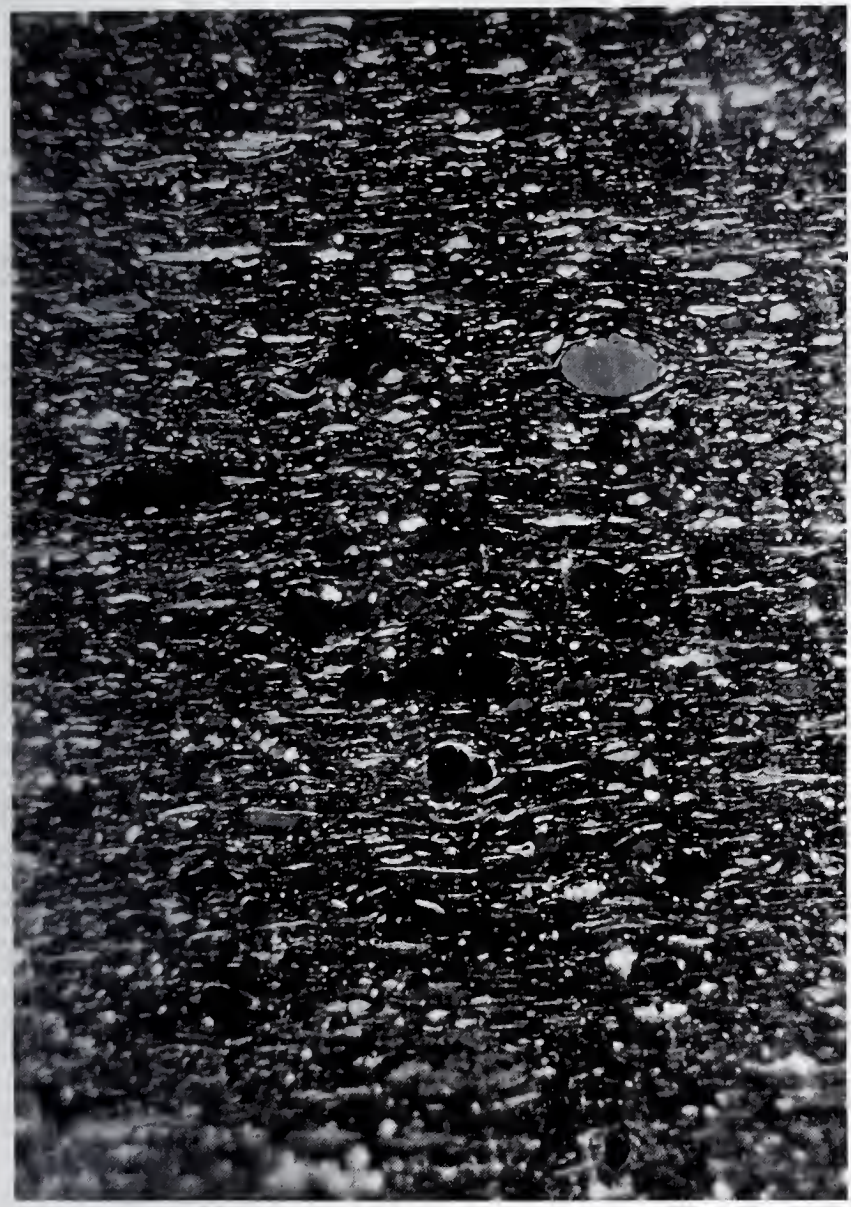


Fig. 17. Thin Cross-section of Cannel Coal from the Top of the Upper Freeport Bed, a Lump of Which Is Shown in Figure 16 and Consists Entirely of Attritus, Composed of Humic Degradation Matter, Spores, Resinous Matter, Fragments of Cuticles, and Some Opaque Matter. (×200)

bed, consists entirely of an attritus; the coal is then of the nature of a cannel coal, and is, by some authors, termed a canneloid coal. (Figs. 16 and 17.)

No coal, or even a layer of any thickness has yet been found to be composed entirely of anthraxylon; but in some layers a coal consists largely of closely packed anthraxylon units. Such a coal is of a

FIG. 18. COAL FROM YORKSHIRE, ENGLAND, COMPOSED OF VITRAIN, LOWER PART, AND CLARAIN, MIDDLE AND UPPER PART. (NATURAL SIZE)

remarkably bright nature but is, however, very fragile and light and differs greatly from a canneloid coal. (Figure 18.)

Ordinarily a coal is compiled of a mixture of anthraxylon and attritus in all imaginable proportions. As the anthraxylon unit consists of greatly varying sizes and thicknesses, from tiny bits to an inch or more in thickness to many feet in length, the arrangement of such mixtures can only be visualized from a sample itself or from a

photograph. A large part, usually the larger part of any coal, consists of a mixture of horizontally layered, thin anthraxylon bands and attritus. Such layers are invariably of a duller appearance and have, in America, been classed as dull coal, and in England, as "clarain." (Fig. 19.) It can well be seen that the proportion of

Fig. 19. Coal from Upper Part of the Pittsburgh Bed in the Bureau of Mines Experimental Mine, Consisting of Numerous Thin Anthraxylon Sheets Interlayered by Attritus

The section shown in Figure 10 was prepared from a similar block (Natural size.)

bright coal, or anthraxylon, to attritus determines partly the brightness or dullness of a coal bed. The brightness of a coal, however, is not alone determined by the proportion of anthraxylon but is also determined by the degree of metamorphism; the greater the metamorphism the higher the gloss of a coal.

ENGLISH TERMS INTRODUCED

About the same time Stopes[9] had rediscovered that according to macroscopical and microscopical appearances and differences by chemical treatment, ordinary bituminous coal can be separated explicitly into four distinctive and visibly differing portions.

These four distinguishable ingredients, all of which in varying quantities are to be found in most ordinary bituminous coals, were named and defined as follows:

1. Fusain—The equivalent of "mother of coal" or "mineral charcoal" of various authors.
2. Durain—The equivalent of "dull," hard coal of various authors the Mattkohle of the Germans, etc.
3. Clarain } Together the equivalent of bright or glanz coal of various authors, the "Glanzkohle" of the Germans Sometimes the "bright" coal of an author seems to be the vitrain only. It has a conchoidal fracture and is brilliant in appeaance.
4. Vitrain }

The first of these terms, fusain, had already been incorporated into the English language from the French by Stevenson[10] to replace the older unwieldy and misleading terms mother of coal and mineral charcoal. The other three terms (durain, clarain, and vitrain) were coined from Latin roots, which were obviously directly descriptive and terminated in "ain" to conform in type with fusain. The descriptions of these four ingredients of banded bituminous coals by Stopes are as follows:

Fusain

"Fusain occurs chiefly as patches and wedges, somewhat flattened parallel to the bedding plane and often with rather square cut ends. It consists of powdery, readily detachable, somewhat fibrous strands. The orientation of the fibrous structure tends to be lengthways in relation to each wedge and the various wedges in a bedding plane lie at various angles to each other, so that in any given light some appear dull and some glisten, according to the direction the light catches the fibers. . . . ."

[9] Stopes, Marie C., On the Four Visible Ingredients in Banded Bituminous Coal: Studies in the Composition of Coal, No. 1. *Proc. Roy. Soc. London*, B, *90*, 470–487 (1919).

[10] Stevenson, J. J., Formation of Coal Beds. *Proc. Amer. Philos. Soc.*, vol. 50, 1911; vol. 51, 1912; vol. 52, 1913.

Durain

"Durain occurs generally as bands of variable thickness and when seen in a face at right angles to the bedding plane they appear parallel to it, though if traced far enough they generally reveal their ultimately lenticular shape. . . . Durain is hard, with a close firm texture, which appears rather granular even to the naked eye. However straight the breaks across it, the broken face is never truly smooth, but if looked at closely always has a finely lumpy or matt surface. Generally, even in the dullest of durain bands a few (or many) flecks or hair-like streaks of bright coal are to be seen. The intercalation of narrow bands of durain and clarain tends to increase at the juncture of the broad dull and the broad bright bands, so that there is no large surface of contact between them which is sharp cut and well defined; even the purest clarain and purest durain tend to have ravelled edges which interlock."[11]

Clarain

"Clarain occurs generally as bands of very variable thickness and when seen in a face at right angles to the bedding plane they appear horizontal to it. Like durain bands they are ultimately widely extended lenticular masses. Clarain even when considerably streaked with durain, has a definite and smooth surface when broken at right angles to the bedding plane and these surfaces have a pronounced gloss or shine. This surface luster is seen to be inherently banded, as well as to have bands of fine durain intercalated between its own bands."

Vitrain

"Vitrain occurs as definite rather narrow bands, sometimes straighter and flatter than the other bands of coal, and sometimes more obviously lenticular. True brilliant vitrain bands are often markedly uniform in thickness for considerable distances and are commonly from about $\frac{1}{8}$ inch to $\frac{1}{4}$ inch but are very seldom more than $\frac{1}{2}$ inch thick. . . . . A single brilliant band does not exhibit the fine layering detectable even in the brightest of clarain, but is a coherent and uniform whole, brilliant, glossy, indeed vitreous in its

[11] Stopes, M. C., and Wheeler, R. V., The Spontaneous Combustion of Coal in Relation to its Composition and Structure: II—The Oxidation and Ignition of Coal. *Fuel*, vol. 12, 1923. See contact between *D* and *C* in Figure 1, facing p. 36 of the journal cited.

texture. The compact, vitreous bands may split up readily in the fingers to small cube-like segments but more generally they break irregularly when forced, as with a penknife point, when the curved irregular faces have a well-marked conchoidal fracture."

These terms were at once generally accepted by the British and by many of the Continental investigators. This classification is only comprehensible with a knowledge of the English coals and to some extent may be applied to the Ruhr coals.

The terms used for the American coals, on the other hand, are incomprehensible to the Europeans without a further knowledge of the American coals. This state of affairs has caused considerable confusion in coal terminology.

Study of the English Coals

A few years ago the writer, when in England, had the opportunity to study the English coals at first hand. In this the matter was cleared up satisfactorily to him at least, and all the differences of interpretations and misunderstandings were cleared away.

The Beeston seam of Yorkshire, England was made the basis of the study. Other coals were studied for comparison as far as time would permit.

It was soon discovered that all of the English coals examined were essentially similar to the American coals in origin and had been laid down in the same manner. Some essential differences were found in that they were somewhat further advanced in coalification, and were on the whole more porous, more granular, and of a brighter appearance than the American coals. The most pronounced difference lies, however, in certain characteristic dull bands, which are not found in the American coals, or are at the most rarely seen—the durain bands. (Figs. 20 and 24.)

The Opaque Matter in Coal. In an examination of any attritus in a coal there is always to be observed certain more highly carbonized or opaque matter among the constituents that compose it. This can be observed in almost any section, but is particularly abundant in the section shown in Figure 21. This opaque matter is of the utmost importance in clearing up the misunderstanding that exists in the terminology of coals. It has been the subject of discussion with coal microscopists for a long time. It is found in smaller or larger proportions in the attritus in all coals (Figs. 9, 11, 12, 13, 14, and 21, of the American coals), cannel coals (Fig. 17), boghead coals (Fig. 22),

and oil shales (Fig. 23). A similar matter is also to be seen in the tissues of thin sections prepared from coal balls. It is, therefore, a common constituent in all fossil plant matter.

The total amount of opaque matter varies in different coals, also in different layers and localities in the same coal; but it often is concentrated in definite layers. This is particularly true of the European coals.

In the English and Ruhr coals the opaque matter is particularly prominent and, according to accounts, in the Saar coals as well. In

FIG. 20. YORKSHIRE COAL FROM THE BEESTON BED, ENGLAND, CONSISTING OF DURAIN, LOWER PART, AND CLARAIN, UPPER PART. (NATURAL SIZE)

the Silesian coals this does not seem to be the case. In certain layers this matter forms the major part of the attritus. Such layers present a characteristic appearance and are distinctly differentiated from the remainder of the coal. It is these bands to which the term durain has been applied. (Figs. 20 and 24.)

Durain in English Coals. When a block of coal containing typical durain bands is ground on a glass plate with a fine abrasive, the durain bands assume a brownish black appearance. When polished to a high degree, the same bands assume a grayish black appearance; while

FIG. 21. THIN CROSS-SECTION OF PITTSBURGH COAL, SHOWING AN ATTRITUS WITH MUCH OPAQUE MATTER INTERLAYERED BY A NUMBER OF ANTHRAXYLON BANDS

Fig. 22. Thin Cross-section of Boghead Coal from Kiskiminetas, Pennsylvania

"Yellow" bodies, in white, are embedded in a ground mass containing much opaque matter. (×200.)

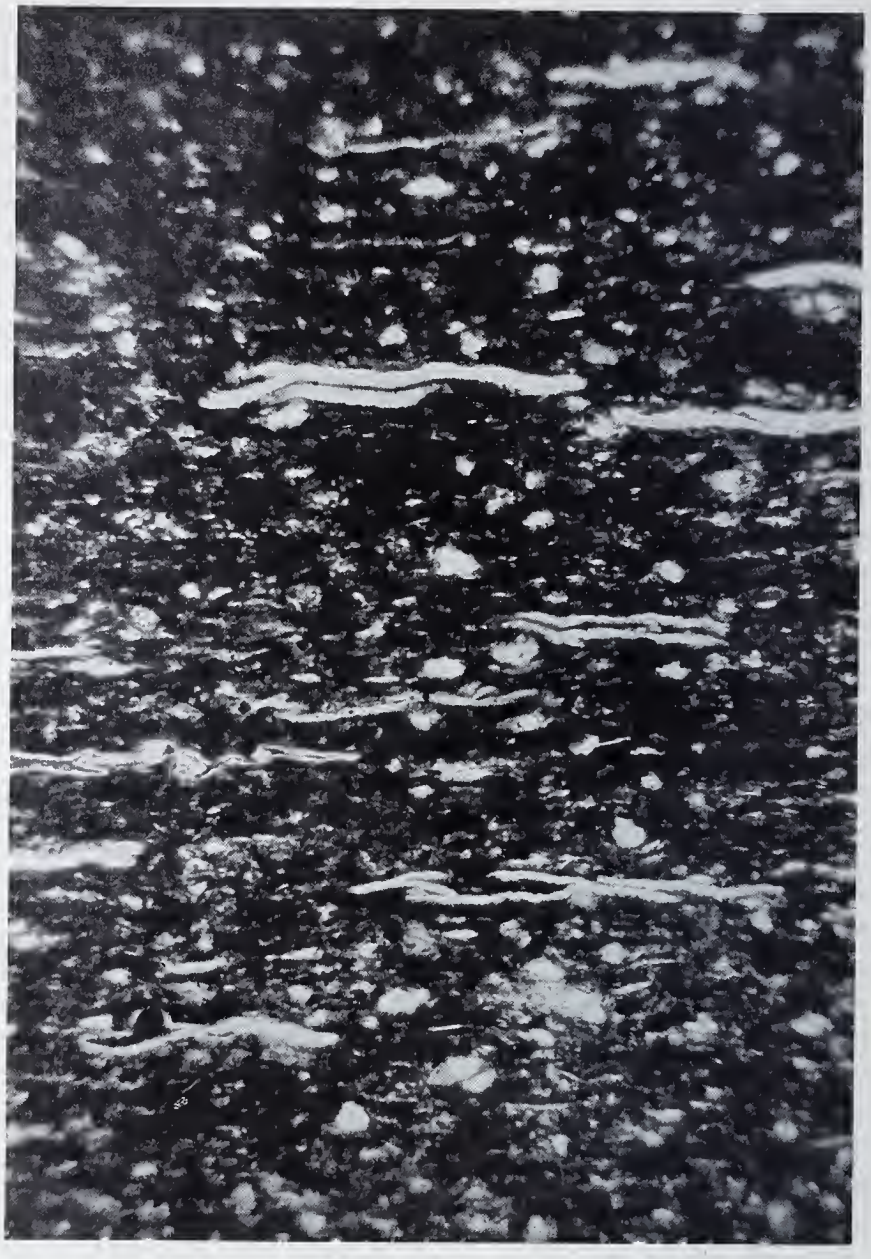


FIG. 23. THIN CROSS-SECTION OF OIL-SHALE FROM THE DEVONIAN OF KENTUCKY

The spores are embedded in a ground matrix consisting of clay, organic degradation matter, opaque matter and pyrite particles. (×200.)

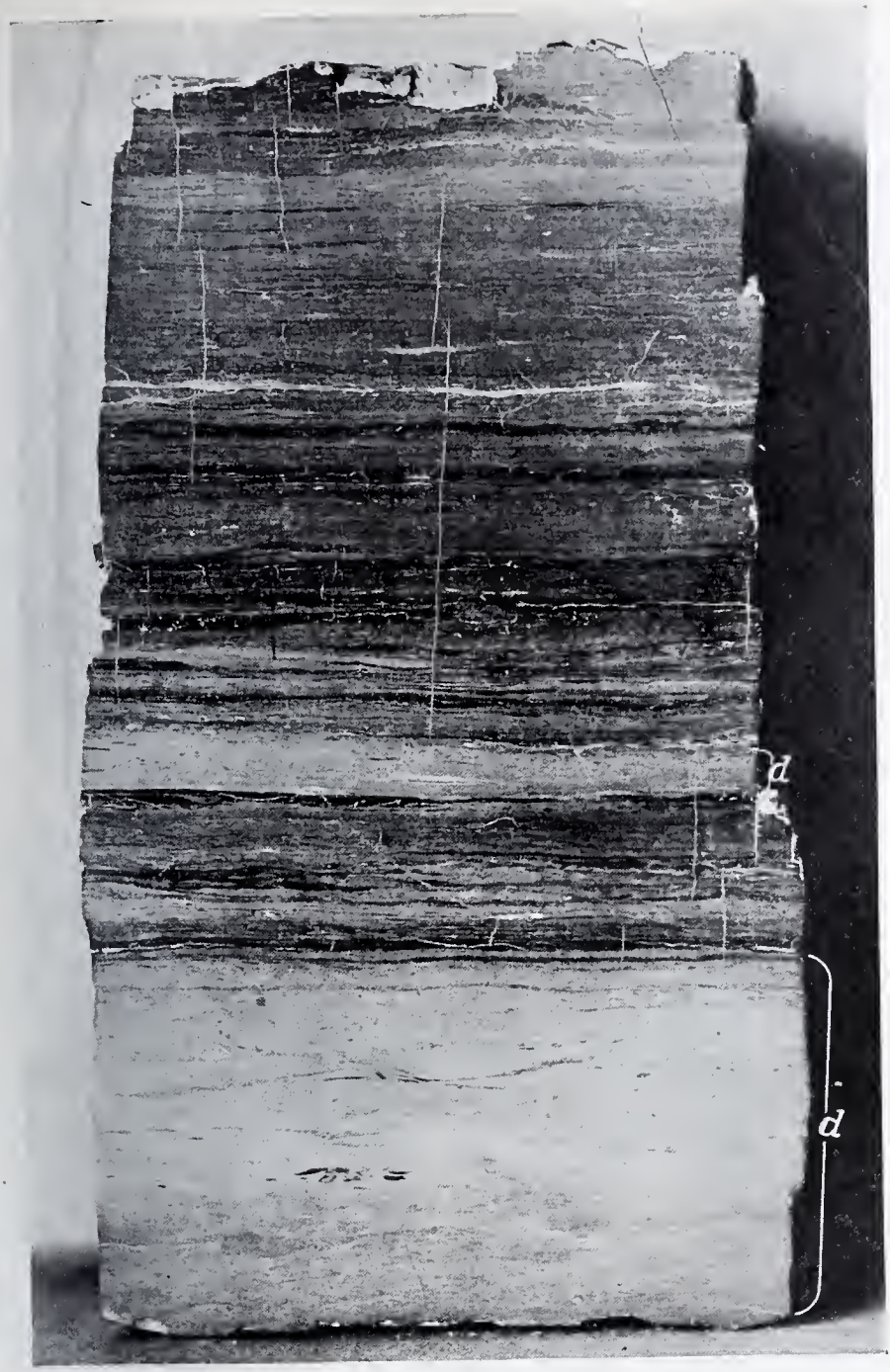


Fig. 24. Coal from the Beeston Seam, England, with Front Surface Polished

This block was pronounced as clarain with durain bands at *d* and *d*. The upper part of this block consists of normal coal, whose attritus consists of material easily rendered transparent with but a relatively small proportion of opaque matter, as shown in Figure 28. Toward the durain band *d*, the proportion of opaque matter increases as shown in Figure 29. In the durain bands *d* the opaque matter predominates as shown in Figure 30. Spores are also abundant. (Natural size.)

the other bands take on a high polish, the durain bands remain dull. In an ordinary thin section—that is, in a section in which the other parts of the coal are transparent—the ground mass of the durain is

FIG. 25. THIN SECTION OF DURAIN OF WIGAN 4-FOOT BED, YORKSHIRE, ENGLAND

This photomicrograph is from an average thin section. The attritus consists largely of opaque matter and spores. The opaque matter appears as a homogeneous mass. (×200.)

still opaque and appears as a homogeneous mass, the spores alone transmitting light. (Fig. 25.) As the section is ground thinner and thinner more and more of the ground mass becomes translucent, and when finely ground, exceedingly thin, and examined at a magni-

FIG. 26. THIN CROSS-SECTIONS OF DURAIN OF ENGLISH COALS

From sections ground very thin and at a higher magnification. *A* and *B*, Wigan 4-foot bed, same sample as shown in Figure 25; *C* from the Grassmore seam, *D* from the Barnsley seam. Note that the ground mass is no longer homogeneous, but very heterogeneous. Spores, much contorted, shown in white. Opaque matter shown in gray to black, depending on the opaqueness of the individual particles. (All ×1000.)

fication between 100 and 200 diameters, the opaque matrix is revealed as a very heterogeneous mass. When examined at a high magnifi-

FIG. 27. THIN CROSS-SECTION OF DURAIN FROM THE BEESTON SEAM, YORKSHIRE, ENGLAND, FROM THE BAND MARKED *d*, LOWER, OF FIGURE 24, SHOWING DURAIN WITH THIN STRIPS OF ANTHRAXYLON. (×200)

cation, at about 1000 or greater, it is shown that the opaque ground mass consists of definite unit particles of greatly varying sizes, form,

and transparency. (Fig. 26.) Some of these particles are now transparent, whereas others are still opaque, with all possible degrees

FIG. 28. THIN CROSS-SECTION OF ATTRITUS FROM THE BEESTON SEAM, YORKSHIRE, ENGLAND, FROM THE UPPER PART OF THE BLOCK SHOWN IN FIGURE 24, THE PART CALLED CLARAIN

The attritus here shown is an ordinary clear material, easily rendered transparent in thin sections, composed of humic degradation matter, resinous matter, spores, and some opaque matter. It is similar to the attritus shown in Figures 12, 13, 14, and 15. (×200.)

of transparency between these two extremes. They present the most bizarre and varied appearance imaginable. It is found that this opaque matter is of the same nature and appearance as the opaque

matter or more highly carbonized matter found in all coals, and is most likely of the same origin.

The size, form, transparancy, and distribution of the particles is so varied that it is impossible to give an adequate description, but the illustrations give a good idea of them.

FIG. 29. THIN CROSS-SECTION OF ATTRITUS OF COAL FROM THE BEESTON BED, FROM BLOCK SHOWN IN FIGURE 24 TOWARDS THE UPPER DURAIN BAND *d*

In passing from the middle part of the block downward the attritus contains more and more opaque matter. Figure 29 shows an intermediate amount of opaque matter. (×200.)

Frequently the durain bands contain thin strips of anthraxylon; these are also of an opaque nature, much more so than those in the clear coal of the same section or block, and appear to be more highly carbonized. (Fig. 27.) These are the stripes in the German Streifenkohle.

The opaque matter is not restricted to the typical durain bands, but is distributed in varying quantities through the whole coal. It is only in such bands where the opaque matter becomes the predominant constituent that the characteristic durain bands become pronounced.

Fig. 30. Thin Cross-section of Durain from the Beeston Seam, from Same Block as Shown in Figure 24, Upper Band *d*

In passing downward from the middle of the block the attritus contains more and more opaque matter until the upper band *d* is reached, where it is a typical durain as shown in this figure. (×200.)

It is common to have a gradual transition from an attritus with none or very little opaque matter (Fig. 28) with increasing amounts (Fig. 29), to one where it predominates (Fig. 30), and forms the typical and characteristic durain.

The origin of the opaque matter has not been worked out satis-

factorily. Rittmeister[12] finds that it is chemically also quite different from the other constituents and concludes that it had a different origin.

In an exact study of a coal it is not the durain bands that become of importance and the object of study, but the opaque matter that constitutes or forms durain.

Recent British Investigations

Kellett,[13] a British investigator, working with Hickling at Newcastle, thinks that the term clarain is superfluous. "Bituminous coal of carboniferous age," he says, "when examined macroscopically, is seen to consist of three components, namely: (1) fusain, (2) vitrain, and (3) durain."

"These components may each occur in the form of distinct and separate lenticles which can be recorded in the vertical section of the seam. Much of the seam consists of the fine intercalations of these constituents in which the individual lenticles are so minute that a separate record of each is practically impossible. A large proportion of the more or less bright coal is made up of such minutely mixed material that the mass has a microscopic or submicroscopic laminated structure, often apparent to the naked eye as a silky sheen. This type of coal constitutes the bulk of what is known as clarain."

This definition harmonizes perfectly with the writer's idea of the compilation of coal. Kellett and Hickling are among a few who have expressed this viewpoint.

When examined microscopically in thin sections, Kellett recognizes the following constituents: (1) anthraxylon, (2) residuum, (3) microspore and megaspore exines, (4) resins, (5) rodlets, (6) cuticles, and (7) fusain.

These constituents, except the residuum, require no further discussion. It will be noted that Kellett does not recognize an attritus, of which the "residuum" is a part, being identical with the opaque matter. Residuum is the name applied by him to the "very dense blackish to deep reddish brown material which is without defined organic structure, and appears as a somewhat granular interstitial matter between individual microscopic ingredients in certain coals."

[12] Rittmeister, W., Eigenschaften und Gefügebestandteile der Ruhrkohlen. *Gluckauf, 64,* 589–594, 624–637 (1928).

[13] Kellett, John G., The Physical Constitution of Bituminous Coal and Coal Seams. *The Colliery Guardian, 137,* 240–242 (1928).

It corresponds, therefore, exactly to the opaque matter which, when more concentrated in certain layers gives rise to the durain bands. Kellett overlooks the fact that other ingredients exist in coal which, without the opaque matter, compose a group of individual constituents that together form an attritus. We are here in want of a descriptive term for this kind of attritus. As described before, the attritus may contain none, or relatively little opaque matter (Figs. 10, 11, 12, 13, 14, and 15.) Such an attritus is easily made transparent and is on the whole of a bright transparency and appearance, as compared with bands that contain much opaque matter. (Figs. 21, 25, 26, 27, and 30.)

TABLE I

TYPES OF COAL RECOGNIZED MACROSCOPICALLY

MACROSCOPIC DESCRIPTION OF THE COAL	MACROSCOPIC BANDS IN THE SEAM	AVERAGE PERCENTAGE OF MICROSCOPIC CONSTITUENT			
		Anthraxylon	Exines, spores, cuticles	Residuum	Fusain
	per cent				
Vitrain	12.3	100.00			
Bright coal	40.00	89.8	7.8	1.8	0.6
Semi-bright	24.5	76.6	12.2	5.6	5.6
Intermediate	1.0	53.5	25.2	10.6	10.16
Semi-dull	5.0	31.5	34.5	27.8	6.2
Durain	13.0	10.7	43.8	35.8	9.3
Fusain	4.2				100.0

Kellett further worked out some interesting relations between the microscopic and macroscopic component and other physical properties of coal. Although experience in the macroscopic examination showed him that they represent a continuous series of mixtures of vitrain, durain, and fusain, yet for practical purposes he could separate coal from fresh, clear surfaces, further into four additional complex bands, besides the three unit bands, vitrain, durain, and fusain, namely,

1. Vitrain, consisting purely of anthraxylon.

2. Bright coal, approaching vitrain in brightness, but obviously a mixture.

3. Semi-bright coal, visibly duller than bright coal, but obviously the bright predominating over the dull.

4. Intermediate dull coal, in which it is difficult to decide macroscopically whether the dull or the bright components predominate.
5. Semi-dull coal in which the dull components predominate.
6. Durain.
7. Fusain.

Kellett thus arbitrarily distinguished seven grades of coal. In an examination of a band 1.5 mm. wide from the base to the top, a pillar of approximately 4 feet of coal of the Maincoal seam in an East Northumberland mine, the microscopic constituents were recorded as percentage of anthraxylon, of resins-cuticles-exines group, of fusain, and of residuum respectively (Table I).

From this table the following points are evident:

(a) Vitrain is composed of anthraxylon.
(b) Durain is microscopically complex and consists mainly of resins, spores, exines, and residuum (opaque matter).
(c) The complex bands are distinguished from durain by the progressive addition of anthraxylon.
(d) The brightness of the coal is proportional to the anthraxylon content.

It further shows a definite relation between the spore-cuticle-resin group, and the residuum; also a definite relation between anthraxylon and fusain.

THE GERMAN TERMINOLOGY

Older Terms

The terms Glanzkohle, Mattkohle, Streifenkohle, and Faserkohle were developed by the earlier German investigators. From them we have the terms bright coal, dull coal, and banded coal. The term Faserkohle or fibrous coal was rarely used except in German papers where it is still used extensively. The fact that the dull coal occurs always intimately mingled with the bright coal has been observed by all investigators, but it remained for Muck to describe and define them systematically and accurately. No better description of these constituents than given by Muck can be found. The term Streifenkohle was first used by Schondorff, according to Muck,[14] who applied it to the Mattcoals intercalated with thin bright strips. This was later applied to all coals and translated into English to banded coal.

[14] See reference 5.

In the German coals it is still by most writers restricted to the Mattkohle or dull coals intercalated with bright bands. In order to understand the terms as used and applied by the Germans it is necessary to understand the nature and appearance of German coals, and knowing them, the terms are easily understood and convey specific meanings. It is also plain that they cannot be applied in general to the American coals with the same meaning.

Nature and Appearance of the Ruhr Coals

The German coals, particularly the Ruhr coals, are of an entirely different macroscopic appearance than our ordinary bituminous coals. They are much more highly metamorphosed and are much brighter as a whole; they are also higher in carbon content. The general rule is that the higher the degree of coalification the higher the gloss of a coal.

The brightness or gloss of a coal is a physical and surface phenomenon. It is brought about by numerous glossy cleavage surfaces. The physical nature of the coal is such that wherever a cleavage is produced the surface is of glossy nature, as if highly polished. In this respect they are like the coals from the Broad Top field of Pennsylvania or like the Pocahontas coals of West Virginia, except that the Ruhr coals are much more compact and not so fragile. The inner or microscopic structure of the Ruhr coals is very similar to any coal, and has often nothing to do with the outer appearance.

Taking a typical Ruhr glanz coal as an example (Fig. 31), although the whole block gives a bright, glossy appearance, no matter what surface, when carefully examined it is shown that it is striped or banded like any coal. This condition is fully recognized by Winter,[15] who recognizes that "vitrit" and "clarit" exist together, but wishes to retain the former term as analogous to glanzkohle. When a face of a cross-bedding is polished, the layering is brought out more sharply and shown to be banded like any bituminous coal. This is also shown by a microscopic examination. The brightness exists largely irrespective of the constituents. This is then a sample of banded coal.

Again, in examining a representative block of Streifenkohle (Fig. 32), it is discovered that the coal has certain bright bands intercalated in a coal that correspond exactly to the durain bands of

[15] Winter, H., Mikroskopische Untersuchungen an Streifenkohlen des Ruhr Bizirks. *Glückauf*, *64*, 653–662 (1928).

FIG. 31. GERMAN GLANZKOHLE FROM THE WILHELM BED, PRÄSIDENT MINE, RUHR DISTRICT

It will be noticed that this typical Glanzkohle is compiled like the lump of Illinois coal shown in Figure 4. This is particularly well shown when a face of Glanzkohle is polished. The black bands in this block correspond to the anthraxylon bands *a* and the grayish bands correspond to the bands *d* of Figure 4. (Natural size.)

FIG. 32. GERMAN STREIFENKOHLE FROM THE WILHELM BED, PRÄSIDENT MINE, RUHR DISTRICT

The gray bands are the Mattkohle and are composed of the same constituents as that of the English durain; the black bands are Glanzkohle and correspond to the American anthraxylon. (Natural size.)

English coals. This corresponds to the original definition of striped coal, a coal consisting chiefly of dull coal with a number of bright strips intercalated.

In the typical mattkohle bands (Fig. 33), on the other hand, the coal is found to be composed entirely or predominantly of the constituent called Mattkohle by the Germans and durain by the British (Fig. 33). These terms are descriptive only with respect to an outward appearance of the coal and reveal nothing of the inner structure.

When Stopes published the terms for the English coals, the

FIG. 33. GERMAN MATTKOHLE

The whole lump consists primarily of Mattkohle, but contains a number of thin strips of Glanzkohle in the upper part. This sample corresponds to the English durain.

Germans accepted them without a clear knowledge of the structure of their own coals nor of that of the English coals.

The terms vitrain, clarain, and durain could not be Germanized nor could they be applied in their entirety to their coals, so the terms were changed to "vitrit," "clarit," and "durit" in order to harmonize them with the generally accepted German minerological suffix "it." Also, because the physical nature of the Ruhr coals differs from that of the English coals, difficulty arose in correlating the components. To overcome this, the definitions also had to be changed to suit the appearances and facts known, as follows:

1. Fusit is that part of the coal appearing in fine layers, or in single fragments, which we have designated as fossil charcoal.

2. Durit are the dull hard strips of coal derived from sapropelite and peat detritus.

3. Clarit is that part of the bright strips revealing plant structure, perhaps more disorganized fossil peat including wood.

4. Vitrit is that part of the bright coal with a conchoidal fracture without recognizable plant structure; perhaps a fossil dopplerite.[16]

Such definitions would indicate that the authors do not comprehend the structure of their own or of the English coals. Later, Stach[17] dropped the term clarit as superfluous, and recognizes only three fundamental components, that either one in itself, or in certain mixtures with one another compile coal. In this he is supported by Lange,[18] Winter, and Rittmeister,[19] in view of the small differences, both chemically and in appearance, and in view of the fact that in a number of coal beds examined no distinction could be made between the two. Others hold to the idea of a clarain. The classification as proposed retains the terms Glanzkohle or Vitrit, Mattkohle or Durit, and Faserkohle (fibrous coal) or Fusit, and all microscopic pictures of a coal may be based on these or the more or less intimate mixtures of these three components. These three types are united by transition stages. A recognition of their transitions by definite terms is not deemed necessary and would not afford as definite a picture as would such terms as duritic-vitrit for striped, bright coal; and vitritic-durit for striped, dull coal, in which at the same time the predominance of the one or the other of the constituents of the mixture is expressed.[20]

The origin of vitrit they recognize in the main to be wood; yet Stach says wood is not the only contributant since herbs have also taken part in its formation, and the most important fact is that vitrit is of humic origin—that is, of land and swamp plants. The cells have secondarily been filled with colloidal matter. Of all the components vitrit has decomposed the most, and for that reason has often lost all of its structure.

Potonie[21] would distinguish between bright coal derived from wood,

[16] Potonie, Robert, *Einführung in die allgemeine Kohlenpetrographie.* Berlin, 1924.

[17] Stach, Erich, *Kohlenpetrographisches Praktikum*, 1928, p. 89.

[18] Lange, Th., Zur Kohlenpetrographie Oberschlesiens. *Zeitsch. d. Obeschles. Berg n. Huttenmannischen Vereins.*, *10*, 1926.

[19] See reference 12.

[20] See reference 17.

[21] Potonic, Robert, Zur Kohlenpetrogrie und Kohlenentstehung. *Zeitsch. Deutsch. Geol. Gesell.*, *78*, 357–380 (1926).

for which he suggests the term "lignitoid vitrit," after Jeffrey, and that derived from cork, "suberitoid vitrit." In case a vitrit is destitute of any structure, he would term it "euvitrit." It is clearly seen from this that the German investigators do not have the conception of vitrit or vitrain as synonymous to athraxylon and to consist of unit constituent. Their vitrit is not a distinct unit. The term is collective and appears to embrace a number of constituents, and from all appearances often includes the same component embraced in America under anthraxylon and attritus together.

A number of German investigators have failed to find plant structure altogether or find it sparingly in vitrain. This is explained in the fact that the Ruhr coals are far advanced in coalification. The structures have therefore been effaced to a considerable extent. This fact is corroborated by Rittmeister who says that the four components in banded coal become more and more alike in chemical behavior and appearance as incoalation progresses, as in the series from flame coals to lean coals.

There is also no clear distinction made between the terms attritus and durain, the two being treated as synonymous. This can not be done. Although all durain is an attritus, all attritus is not durain. Similarly, durain and cannel coal are invariably classed alike. Durain is never a cannel coal, nor is cannel coal ever a durain. The constituents of these two components as a whole, while both of the nature of an attritus, differ vastly in origin, appearance, and chemical behavior.

The term attritus is the broader one and may include any or all of the constituents comprising humic attritus, durain, cannel coal, or boghead coal. In other words, an attritus may be of the nature of a humic or ordinary coal attritus, a durain, a cannel coal, a boghead coal or a mixture of any two, three, or all in varying proportions.

It is plain that if coal investigators would recognize distinctly the two main components of coal, anthraxylon and attritus, the great confusion and uncertainty would disappear. It must be strictly kept in mind that anthraxylon is that constituent in coal existing in definite units of greatly varying sizes and forms, but always derived from the woody tissues of plants. In the majority of such units, plant structure or structure derived from the original structure is plainly discernible; often, however, such structures are revealed with difficulty; but it is rare that all signs and indications of such structures have been totally effaced. The preservation of the structure depends

plainly upon the mode and degree of transformation of the plant substances into peat and upon the later coalification processes of the transformation of peat into the higher ranks of coal. The higher the rank of coal, or in other words the greater the metamorphism, the more effaced is the plant structure. Secondly, it must be borne in mind that the attritus includes a large number of derivatives and may be grouped into a number of classes.

II. RECENT CONTRIBUTIONS TO THE ORIGIN OF COAL

ANTHRAXYLON AND OTHER WOODY AND HUMIC DEGRADATION MATTERS

We have seen that in the ordinary banded coals by far the larger part consists of anthraxylon bands or sheets and humic attritus. This part, as far as is now known, is largely derived from the woody or lignified tissues of plants.

These components have their exact counterpart in the woody residues in peat, in which these components are comprised under the collective terms "humins" or "humic acids." These, therefore, become important components in the study of all coals. It must, however, not be construed that their constituents are present in the form of a homogeneous jelly; quite the opposite. The humic matter is almost entirely present in the form of fragments of tissues in which the cell structure is fairly well preserved. They consist of pieces of rotten wood.

In recent years considerable advance has been made in the knowledge of the humins in respect to origin and nature, although the chemical structure still remains unknown. The discussion will be taken up from the microbiological standpoint.

PEAT FORMATION

A large part of the study of peat formation is microbiological and chemistry of decay, in other words, rotting is the most important phase. It can roughly be divided into three phases: (1) decomposition entirely in the air; (2) decomposition in a zone, more or less fluctuating, between completely aerated zone and the zone of complete privation of air; and (3) complete submersion and privation of air.

In the established peat deposit, these three phases are merely stages, since after a considerable lapse of time they gradually and

simultaneously change from the first into the second and from the second into the third stage.

The first of these stages is by far the most important as in it the most important eliminating and the greatest changes take place through decay. Fungi are the initial and the most important organisms. Bacteria follow the fungi. The statement has been made that bacteria will not initiate decay of wood aerobically.[22] This question has not yet been confirmed. But inoculations have proved that bacteria exist and are active in wood rotting in the air. In the semi-decomposed condition wood is further infested by actinomyces, flat worms, round worms, and all kinds of insect larvae and burrowing insects, as well as crustaceae. All of these organisms combined bring about the advanced stage of decomposition, disintegration, and comminution as it is generally found in any peat deposit. By the time this debris is covered up by debris subsequently formed, only the smaller part is in the shape of fragments of rotten wood; the larger part is in the form of an attritus.

As the debris is covered up more and more and the moisture becomes greater and greater, up to the time when complete immersion ensues, the nature of the decomposing agencies change. Fungi cease to exist completely, actinomyces become rare, so do insects and other organisms. Bacteria are now both aerobic and facultative anaerobic. Disintegration and decomposition are materially slowed up.

This is the zone, it should be noted, in which and on which the contributing plants grow. The roots of these plants remain relatively close to the surface. These as well as a considerable number of prostrate stems are eventually covered without being subjected to the agencies prevalent in the first zone or stage and are still sound and intact when completely buried.

When finally the debris, together with the roots and unmacerated stems is more deeply buried or submerged under a very wet layer of peat, all life except that of the anaerobic bacteria has disappeared. That bacteria exist in peat deposits, and to considerable depths, has now been proved sufficiently.

[22] Berthold, Erich, Zur Kenntnisse des Verhaltens von Bakterien im Gewerbe der Pflanzen. *Jahrb. wiss. Botanik*, *57*, 387–460 (1917).

Bacteria in Peat

The writer and his assistants have made a large number of inoculations in a number of peat deposits from the surface to the bottom, deposits varying in depth from a few feet to about 30 feet. In only a few cases were cultures not obtained.

Large samples obtained by cutting columns 20 inches square from top to bottom, as well as small samples by means of a sounder were taken into the laboratory. From these, inoculations on wood, in the form of sawdust and shavings and other plant material were made. Invariably cultures have been propagated on these materials, and are still active. A mineral culture solution containing available nitrates is essential in such culture. When the nitrates are depleted, evolution of gas slows up or ceases. When culture solutions are again added the reaction is resumed at once. Also, when tubes are filled with fresh peat and placed in an incubator, a reaction almost always starts, but usually very slowly. When, however, culture solutions containing available nitrogen are added, the evolution of gas becomes much more copious. The gas consists mostly of CO_2 and CH_4. It is thus shown that nitrogen is essential in the growth and activity of bacteria in peat the same as in soils. The kind of material, the kind of wood, and temperature are also important factors.

The experiments show also that bacteria may be dormant in the deposit, but as soon as subjected to favorable conditions, such as higher temperatures and available nitrogen, they quickly resume activity.

Bacteria in Brown Coals

It has long been a matter of speculation as to how long such bacteria remain alive. In view of the fact that they have been found at considerable depths, down to 30 feet, it would indicate that bacteria must have survived a long time.

Recently, considerable light has been thrown on this matter by the investigation of Lieske and Hofman,[23] of the Kaiser Wilhelm Institute für Kohlenforshung, at Mühlheim. A number of brown coal beds were carefully investigated. They found that the entire mass of the beds from top to bottom, where a mechanical contamination was impossible, was infested with bacteria varying from 5 to 100 speci-

[23] Lieske, R. and Hofman, E., Untersuchungen über die Mikrobiologie der Kohlen and ihrer naturlichen Lagerstätten: 1—Kie Mikrofloro der Braunkohlengruben. *Brennstoff-Chemie*, *9*, 174–178 (1928).

mens per cubic centimeter. In most cases they belonged to the group *Bacterium Fluorescens;* in only two cases were they found to be of another type, an abnormal kind, resembling those of the *Mesentericus* group. It was also found that out of the very large number of bacteria known to infest the earth only a few could be propagated on brown coal, and these belonged to the group *Bacterium Fluorescens.*

Bacteria in Bituminous Coals

Recently, these same investigators have made the astounding assertion that the coal of the Ruhr district is generally infested with bacteria.[24] In only a few cases were the coal samples tested found to be sterile. The bacteria belong chiefly to the *Subtilis* and *Mesentericus* groups. A specific flora as was found in the brown coals, however, was not found in the Paleozoic coals. These bacteria were not pathogenetic.

These findings are tremendously interesting and important, if true. It is, however, not so much the question as to how far back they can be traced into the ancient rocks, but what influence have they had on the metamorphosism of the coal since its deposition.

This leads us now into decay of wood and humus formation.

DECOMPOSITION OF WOOD

Decomposition of Wood in the Air

Since humus, humins, or humic acids have their origin chiefly in wood, and woody or lignified tissues the chemistry of decay of wood is of the utmost importance. It is in this that important advances have been made in recent years.

Composition of Wood

In order to comprehend the significance of this problem it is well to recall the components that comprise wood.

The most important constituents of wood are cellulose and lignin, both totally insoluble, and the hemicelluloses, partly soluble in water. Mineral matter, starch, and proteins are always present in small amounts. Wood also contains a variable amount of secondary constituents manufactured by the living cells, but which do not form

[24] Lieske, R. and Hofman, E., Untersuchungen über die Microbiologie der Kohlen und ihrer natürlichen Lagerstätten: 2—Mitteilung: Die mikroflora der Steinkohlen gruben. *Brennstoff-Chemie, 9,* 282–285 (1928).

part of the wood proper, such as resins, tannins, pigments, fats, oils, wax, gums, oleoresins, volatile oils, etc. Pectin is also present, but whether a primary or secondary constituent is problematical.

The term "hemicelluloses" is a collective one and at best very indefinite. They are polysaccharides, which bridge the gap between the insoluble cellulose and the definitely recognized carbohydrates like starch. It seems that it is impossible to know where cellulose ends and where hemicellulose begins. Under this term are collected glucosans, mannans, levulans, galactans, xylans, and arabans; further, the mixed polysaccharides, mannogalactans, galacto-mannans, xylo-mannans and others.

In what relation cellulose, lignin, and the hemicelluloses exist is not definitely known. It is as much disputed now as it was 50 years ago

TABLE II

SUMMATIVE ANALYSES OF AMERICAN WOODS, ACCORDING TO DORE

	REDWOOD	YELLOW PINE	SUGAR PINE
Per cent extracted by benzol	0.34	2.22	2.84
Per cent extracted by alcohol	4.39	1.49	1.90
Cellulose	54.89	57.72	59.18
Lignin	34.50	29.47	29.50
Soluble pentosans (xylan)	3.67	3.49	1.86
Mannan	3.21	6.37	6.63
Galactan	0.50	0.78	0.50
Total	101.50	101.54	102.41

whether lignin and cellulose are chemically combined, admixed, or adsorbed in wood.

The precise amounts and relative proportions of the constituents of wood do not only vary considerably with the different species of wood, but also in different parts of the same tree and in wood of the same species. The yields also vary some with the methods used to separate them.

Table II, taken from the "Chemistry of Wood" by Hawley and Wise,[25] will give some idea of the amounts of constituents.

[25] Hawley, L. F., and Wise, E., *The Chemistry of Wood.* Chemical Catalog Co., 1926, p. 182. See also *The Chemistry of Cellulose and Wood* by A. W. Schorger, 1926.

Wood Decay

In wood decaying in the air the highly complex components pass into products of decreasing complexity until finally under favorable conditions all pass into carbon dioxide (CO_2), water (H_2O), methane (CH_4), and hydrogen (H_2). Between sound wood and the final products must exist a series of intermediate products.

Hawley, Fleck, and Richards say that the general conclusion can safely be drawn from a series of investigations that the pentosans in cellulose are among the very first constituents of wood which are attacked by decay and that, in proportion to the amount present, they are more rapidly removed than the hexosans in the cellulose.[26]

When wood begins to decay a rapid fall in cellulose is soon noted; the lignin complex, being far more resistant than the cellulose, remains almost constant. As decay progresses there is a decided increase in the less stable β cellulose, a large loss in the more stable α cellulose and a slight loss of the γ cellulose.

As decay proceeds, the cellulose disappears more and more, leaving finally little or nothing but the so-called humin, popularly known as rotten wood, a product of the original lignin of the lignocellulose proper. Recent experiments with fir wood containing 60 per cent cellulose after six months rotting contained 26.8 per cent; after one year 10.90 per cent; and after three years 6.05 per cent. The lignin complex lost about 3 per cent in three years and then remained constant. It must be remembered, however, that wood contains a number of adventitious substances like fat and waxes and others. These are not attacked by organisms of decay, as shown in the ether extracts.

Table III shows the difference in sound and rotten spruce wood and Table IV shows the difference in sound heartwood, partly rotten heartwood, and more completely rotten heartwood of Douglas fir. The account and tables are from studies made on materials that were infected with mixtures of organisms. Bray and Andrews[27] later carried on investigations at the Forest Products Laboratory, Madison, Wisconsin, to show the chemical changes brought about in wood when infected by specific organisms in pure culture. Table V gives the results.

[26] Hawley, L. F., Fleck, L. C. and Richards, C. A., Effect of decay on the chemical composition of wood. *Ind. and Eng. Chem.*, *20*, 504–507 (1928).

[27] Bray, M. W. and Andrews, T. M., Chemical Changes of Ground Wood during Decay. *Ind. and Eng. Chem.*, *16*, 137 (1924).

TABLE III

CHEMICAL COMPOSITION OF SOUND AND ROTTEN SPRUCE WOOD, PER CENT*

	SOUND SPRUCE CONTAINED	BADLY ROTTED SPRUCE CONTAINED
	per cent	*per cent*
Lignin	28.30	38.20
Cellulose, total	58.58	42.00
α Cellulose	63.55	17.00
β Cellulose	10.37	74.60
γ Cellulose	28.08	8.40
Pentosan	11.88	8.50
Methylpentosan	1.88	3.77
Ash	0.17	0.61
Cold-water soluble	2.30	6.58
Hot-water soluble	3.90	11.92
1 per cent NaOH soluble	8.83	44.00
7.14 per cent NaOH soluble	18.80	62.36
Ether soluble	1.24	1.47

* Bray, M. W., and Staidle, J. A., The chemical changes involved during infection and decay of wood and wood pulp. *Ind. Eng. Chem.*, *14*, 33–40 (1922).

TABLE IV

COMPOSITION OF DECAYED WOOD, PER CENT*

	SOUND WOOD	PARTLY ROTTEN WOOD	MORE COMPLETELY ROTTEN
	per cent	*per cent*	*per cent*
Cold-water soluble	4.03	1.76	1.16
Hot-water soluble	2.23	4.19	7.77
Alkali soluble	10.61	38.10	65.31
Cellulose	58.96	41.66	8.47
Acid hydrolysis	0.71	0.28	0.17
Pentosan	7.16	6.79	2.96
Methylpentosan	2.64	3.56	6.06
Methoxyl group	3.94	5.16	7.80
Moisture	9.81	10.63	9.09
Ether extract	2.71	2.05	2.72
Ash	0.15	0.15	0.65

* Rose, R. E., and Lisse, Martin, W., The Chemistry of Wood Decay. *Ind. Eng. Chem.*, *9*, 284–287 (1917).

During the process of decay, lignin does not decay uniformly and probably proceeds very slowly by stages. Few experiments have been carried on and little has been recorded that furnishes definite knowledge as to the lignin degradation or so-called humus formation. Much more information is wanted on this point.

TABLE V

ANALYSIS OF GROUND WOOD BASED ON EQUAL WEIGHTS OF ORIGINAL SAMPLE, PER CENT, ACCORDING TO BRAY AND ANDREWS CITED

SAMPLE	ORGANISM OR CULTURE NUMBER	STORAGE TIME, MONTHS	LOSSES DUE TO DECAY, PER CENT	WATER SOLUBLE		1 PER CENT ALKALI SOLUBLE	LIGNIN	CELLULOSE	CELLULOSE	CELLULOSE	CELLULOSE	PENTOSAN	METHOXYL	COPPER NUMBER
				Cold	Hot									
2544	Sound	0	0.0	0.0	1.2	10.1	29.7	60.0	36.3	14.7	9.0	12.0	5.5	4.4
100	4620-2	6	27.12	8.1	13.1	40.0	27.7	26.8	5.1	18.0	3.5			
102	4620-2	12	49.5	7.5	11.1	33.4	26.7	10.9						
182	4620-2	36	62.4		6.2	26.3	26.7	6.05				2.56	2.7	8.65
130	*Fomes roseus*	6	10.3	2.9	5.7	29.6	30.6	44.3	22.0	17.2	5.1			
131	*Fomes roseus*	9	12.94	3.2	4.9	29.2	30.3	43.8						
157	*Lentinus lepideus*	6	21.54	7.5	11.8	41.0	28.8	32.1	16.5	12.0	3.5			
158	*Lentinus lepideus*	9	30.31	9.7	15.7	40.6	28.6	25.8						
106	4620-1	6	22.2	10.8	13.7	40.8	30.7	29.0	6.9	19.8	2.3			
107	4620-1	9	33.11	11.1	15.3	41.6	28.8	18.2						
108	4620-1	2	38.63	9.3	13.0	38.0	28.5	16.9						
148	*Peniophora tabacina*	6	13.5	4.8	9.0	34.9	27.7	40.5	22.5	13.9	4.2			

Composition of Rotted Wood

Thoroughly rotten wood consists partly of water-soluble substance, partly of alkaline-soluble substances, and an insoluble residue much richer in carbon. A reliable record was made by Wehmer a number of years ago.[28] Since then a number of similar observations have been made. He separated rotten fir wood, *Picea exelsa*, into the following substances:

[28] Wehmer, C., Zum Abbau Holzsubstanz durch Pilze. *Ber.-Deutsh. Chem. Gesel.*, *48*, 130–134 (1915); *Rev. Koll Zsch.*, *16*, 181 (1915).

Humin I. Cold-water soluble. A brown-black, glistening, hard lack easily soluble in water, extractable with hot water.

Humin II. Hot-water soluble. A coal-like, dull powder, composed of small spherical grains of 1 to 5 mm. in diameter, extractable with hot water, precipitating on cooling as a brownish gray sediment.

Humin III. Alkali (2 per cent) soluble. Glistening, brownish black, brittle pieces, insoluble in water, extractable with 2 per cent solution of soda as a dark brown solution, coagulating with acids in fluffy flakes.

Humin IV. An insoluble peat-like compact brown residue retaining the woody structure. Table VI shows the percentage composition:

TABLE VI

COMPOSITION OF SUBSTANCES IN ROTTEN FIR WOOD, PER CENT

SUBSTANCE	C	H_2	O_2	PER CENT OF TOTAL SUBSTANCE
	per cent	*per cent*	*per cent*	*per cent*
Humin I	46.4	6.0	47.5	12.5
Humin II	51.6	5.6	42.8	1.5
Humin III	64.1	8.0	28.0	7.4
Residue	60.5	9.35	30.14	51.6
Water				27.0

A sample of wood containing 51 per cent carbon during complete decay yielded (1) 50 per cent of CO_2, H_2O, and some fungal remains; and (2) 50 per cent of humified wood with a carbon content of 56.8 per cent. The humified wood was separable into (*a*) 15 per cent water-soluble substance with a carbon content of 46.4 to 51.6 per cent, (*b*) 35 per cent alkali-soluble substance with a carbon content of 64 per cent, and (*c*) 50 per cent insoluble substance with a well-preserved structure with traces of cellulose.

Here are cited only a few observations of a large number made in the last few years:

This matter is being further investigated in the Microscopic Laboratory of the United States Bureau of Mines. So far, our findings check well with the previous investigations. Work is also under way to determine more definitely the nature and chemistry of the various fractions.

Anaerobic Decomposition of Wood

That wood is decomposed anaerobically has already been referred to, but as yet nothing definite is available on the decomposition of wood under strictly anaerobic conditions.

We have now in the incubator a number of cultures in bottles, flasks, and test tubes containing wood in the form of shavings, sawdust, and excelsior, and cellulose in the form of filter paper inoculated from peat and other sources with and without mineral culture media under strictly anaerobic conditions. All are active; some of them were started over a year ago and are still as active.

We hope to discover what becomes of the cellulose, lignin, and the hemicelluloses, whether humus is formed under anaerobic conditions and what is its source. We have found that nitrogen, available in nitrates, is essential and that the activity depends upon temperature, the kind of wood, particularly upon the resinous content, and the acidity of the media. The gas analyzed consists chiefly of carbon dioxide and methane.

HUMUS OR HUMIC ACIDS

The nature of humus has been the object of lively discussion throughout the nineteenth century and up to the present time, and as to the true chemical nature or constitution we are not much further than at the beginning of this century.

As characterized by Tropsch,[29] three characteristic stages can be recognized in humic substances. The first stage exists in peat and in the younger brown coals when they are of an acid nature and soluble in alkalies. The second stage is to be found in the older brown coals and the lignites, when they are no longer of an acid nature, but may be considered as an anhydride of humic acid, and no longer soluble in weak alkalies in the cold, but may be brought back to the acid stage by boiling in alkali solutions. In the third stage found in bituminous coals they are insoluble in boiling alkali solutions, but may be brought back by auto-oxidation at higher temperatures after the method of Boudonard,[30] by pressure oxidation with alkali according to Fischer and Schrader,[31] by oxidation with hydrogen peroxide,

[29] Tropsch, Hans, Unsere heutigen Kenntnisse neber den humus anteil und die Bitumina der Kohlen. *Brennstoff-Chemie*, *8*, 369–374 (1927).

[30] Boudonard, O., Action de l'air et des oxidants sur les charbons. *Compt. rend.*, *148*, 284–286 (1909).

[31] Fischer, Franz, and Schrader, H., *Abt. Kohle.*, *4*, 342 (1919).

after Francis and Wheeler,[32] by mild oxidation in the air, both at normal and raised temperatures, which changes them to a form soluble in alkalies[33] as well as by oxidation through nitric acid.[34] These reactions unmistakably show a genetic relation between the three stages, also that no basic changes can have taken place in the transformation of one into the other.

The general opinion of investigators is that it is not a unit substance nor a single class of compounds, but a mixture of a considerable number of chemical compounds.

To the latter opinion, the works of Schreiner and Schorey[35] lend considerable weight; they have extracted a considerable number of definite compounds from soil humus. However, soil humus can not be compared in full with humus derived from wood direct through decay.

Van Bemmelen,[36] and Baumann and Gully[37] hold that humins are colloids derived from plant substances of a similar nature. As colloids they are either in the form of hydrosols or hydrojells and as such they have a high coefficient of absorption and will absorb many substances, particularly inorganic salts which cause their precipitation and give them the appearance of acids. Baumann and Gully, however, find that some true acids are present in the mixture.

Sven Oden,[38] one of the foremost investigators on humins, offers proof that the humins are definite compounds, also that they are true acids, that their equivalent weights can be determined by their electro-conductivity, and that they have 3 or 4 replaceable hydrogen ions forming salts with alkalies.

[32] Francis, Wilfrid, and Wheeler, R. V., *Jour. Chem. Soc.*, *127*, 2236–2245 (1925).

[33] Francis, Wilfrid, and Wheeler, R. V., The Oxidation of Banded Bituminous Coal at Low Temperature: Studies in the Composition of Coal. *Jour. Chem. Soc.*, *127*, 112–125 (1925).

[34] Francis, Wilfrid, The Classification of Coal in the Light of Recent Discoveries with Regard to its Constitution. Tech. Pub. No. 156, Classification of Coal. *Am. Inst. Min. and Met. Eng.*, 1928, pp. 47–67.

[35] Schreiner, Oswald and Schorey, Edmund, The Presence of Arginine and Histidine in Soils. *Jour. Biol. Chem.*, vol. 8, pp. 382–384 (1910).

The Isolation of Harmful Organic Substances from Soils. Bur. Soils, U. S. Dept. Agri. Bull. 53 (1909).

[36] Van Bemmelen, J. M., Die Asorption. Dresden (1910).

[37] Baumann, Anton and Gully, Eugen, Untersuchungen über die Humussauren. *Mitt. K. Bayr. Moorkulturanst*, *4*, 31–156 (1910).

[38] Oden, Sven, The Humic Acid in Sphagnum Peat. *Ber. d. d. Chem. Ges.*, *45*, 651 (1912).

Several of those who believe that humus is a definite substance have ventured to give structural formulae, but are not concordant. Others are too prudent even to suggest such a formula.

Tropsch[39] believes that it is doubtful whether it is possible to obtain the constitution formula with the present knowledge of organic chemistry. Fuchs[40] has found evidence of humates and free humic acid in the brown coals. The calcium of humic acids, for example, will be taken up by the humic acid and calcium humate is formed and acetic acid set free. The following reactions may take place:

$$2\ \text{Hum.H.} + \text{Ca}(\text{CH}_3\cdot\text{COO})_2 = \text{Ca}(\text{Hum})_2 + 2\text{CH}_3\text{OOH}$$

Further, the sodium of a sodium humate may be exchanged for the calcium of a calcium acetate:

$$\text{Ca}(\text{Hum})_2 + 2\text{CH}_3\text{COO Na} = 2\ \text{Hum.Na} + \text{Ca}(\text{H}_3\text{OO})_2$$
$$2\ \text{Hum.Na} + \text{Ca}(\text{CH}_3\text{COO})_2 = \text{Ca}(\text{Hum}) + 2\text{CH}_3\text{OO Na}$$

These reactions make it possible to determine the free acids and the humates.

The writer has found similar substances and reactions in peat humin.

SOURCE OF HUMINS

The most recent investigators definitely indicate that lignin is the chief source of humin and that cellulose is only an indirect source.

Hoppe-Seyler[41] had already shown that cellulose, when decomposed by microörganisms, did not form humin. Benni[42] went still further in saying that neither artificial nor natural agencies led to the formation of humins from cellulose. Trussow[43] showed that cellulose does not give rise to humus, but found that humic acids were formed from protein derivations, particularly those that contain a pyrrol- or a phenol-group, also from lignin, tannins, and fats. Re-

[39] Tropsch, Hans, Unsere heutigen Kenntnisse über den Humenauteil und die Bitumina der Kohlen. *Brennstoff-Chemie*, *8*, 369–374 (1927).

[40] Fuchs, Walter, Ueber die untersuchung von Braunkohle und Steinkohle. *Brennstoff-Chemie*, *8*, 337–340 (1927).

[41] Hoppe-Seyler, F., *Zeitschrift physiol. Chem.*, *13*, 66–121 (1889).

[42] Benni, S.. *Zeitschs. Naturwiss.*, *69*, 145–176 (1926).

[43] Trussow, A. G., *Contributions to the Study of Russian Soils.* Petrograd. 26–27 (1917).

cently, Waksman, cited later, has added considerable knowledge to this point.

Fischer and Schrader[44] were the first to call general attention to this phenomenon and proposed the lignin theory.

FISCHER AND SCHRADER'S LIGNIN THEORY

According to the postulates of the lignin theory, cellulose disappears completely through activities of microörganisms, being finally decomposed to the lower aliphatic acids. In consequence, the biological resistant lignin is accumulated but is soon changed. By an accompanying loss of acetyl- and methoxyl-groups it is transformed into an alkali-soluble humic acid. This is further transformed into alkali-insoluble humins, and the latter is transformed by incoalation to true coal.

Fischer and Schrader's conclusions are based on their own experimental work and from the studies of other investigators chiefly from a chemical standpoint. Cellulose and lignin are given the chief consideration. The theory is based upon the distinct chemical difference of cellulose and lignin, and that during turfication, cellulose is decomposed into CO_2 and H_2O by means of microörganisms and disappears. Lignin, therefore, must accumulate during increasing age indicated by an increase in methoxyl content of peat with increasing age, and by a decrease in cellulose and its decomposition products. The same must be true of rotting wood. As brown coals reveal very little methoxyl and the bituminous coals none, there later must be shown a reduction of methoxyl content, perhaps in that through saponification methoxyl groups change over into hydroxyl groups. They assumed that phenolitic compounds must be formed through saponification of acetyl groups of the neutral lignin and this acid compound is nothing else than humic acid. Humic acid should, therefore, have the same fundamental constitution as lignin and should contain methoxyl. A further change could then take place through the disappearance of methoxyls and in increase in hydroxyls.

[44] Fischer, Franz, and Schrader, Hans, Ueber die Enstchung und die chemische Struktur der Kohle. *Brennstoff-Chemie, 2,* 37–45 (1921); Neue Beitrage zur Entstchung und chemische Struktur der Kohle. *Brennstoff-Chemie, 3* (1922).

The Fischer-Schrader lignin theory aroused much criticism and unfavorable comment, but it at once stimulated research on the origin of coal, and as it has few vulnerable points, it has stood well the test of time. But the theory still has its antagonists, and as yet has not been accepted as a whole, and probably can not be accepted without slight modification.

Since publication of Fischer and Schrader's paper in 1922, many data on the matter have been obtained and have cleared up many dark spots. The chemistry of decay has been greatly advanced, particularly through the Forest Products Laboratory at Madison, Wisconsin, as well as at other laboratories. From this end the Fischer-Schrader lignin theory receives its greatest support. Waksman[45] of the New Jersey Agricultural Experiment Station has shed much light on formation of humus and decomposition of cellulose.

HUMUS FORMATION FROM CELLULOSE

The most recent developments in the decomposition of cellulose and the formation of humus in the soil from cellulose has been summarized by Waksman[46] as follows:

"Cellulose is decomposed in nature mainly through the agencies of fungi, most active under acid and aerobic conditions; aerobic bacteria, most active in neutral, weakly basic and slightly acid conditions, well aerated and containing carbonates ($CaCO_3$); actinomyces most active under conditions like those of aerobic bacteria and anaerobic bacteria, particularly in moist and aerobic conditions.

"The decomposition of cellulose is, of course, always accompanied by the growth of the organisms in considerable amounts. The body substances are built up synthetically from the cellulose and the nitrogen of the culture media, and thus contain nitrogen.

"Since the cell substances formed by the organisms contain a definite amount of nitrogen, and since the cellulose-decomposing organisms are unable to fix atmospheric nitrogen, the decomposition of cellulose results in the liberation of energy which enables the organism to bring about the transformation of simple inorganic nitrogen into complex organic nitrogen compounds which become a

[45] Waksman, S. A., and Skinner, C. E., Microörganisms Concerned in the Decomposition of Celluloses in the Soil. *Jour. Bacteriology, 12*, 57–84 (1926).

[46] Waksman, S. A., Cellulose als eine Quelle des Humus im Erdboden. *Cellulose Chemie, 8*, 97–104 (1927); The Microbiological Complexes of the Soil and Soil Deterioration. *Jour. Am. Soc. Agron., 18* (2), 137–142 (1926).

part of the decomposing organisms. It has been determined that there is a definite relationship between the cellulose decomposed and the nitrogen used by the organisms. This relationship for fungi and aerobic bacteria is 30:1. Through other microörganisms not attacking cellulose these microörganisms with other organic matter are again decomposed and a part of the nitrogen is again changed into the inorganic form; this may again be assimilated in the presence of an excess of cellulose and again take part in the relationship of cellulose to nitrogen. This cell substance may amount to 20 or 30 per cent of the decomposed cellulose. When this cell substance decomposes, certain parts of it, being more resistant, remain and always constitute a part of the humins. In their behavior they resemble ordinary humic acids, and are soluble in alkalies and contain 3 to 5 per cent of nitrogen.

"These results confirm the theory that humus is composed of two kinds of substances of different origin: (1) plant remains that resist decomposition like lignin, cutin, resins, etc. and (2) compounds derived from synthetic cell substances formed by microörganisms, as body substances, using cellulose, pentosans, starch, sugar and proteins as energy supply.

"These humins are collected only at low temperatures under anaerobic and acid condition. Under aerobic and alkaline conditions, and raised temperature, these humins, together with lignin, fats, waxes and body substances of microörganisms, are decomposed by certain specific organisms."

Marcusson's Oxycellulose Theory

The theory that humins are all derived direct from cellulose as well as from lignin has, however, not been without support in recent years. Marcusson,[47] among others, has been particularly active in supporting this idea. He refutes the observations of Rose and Lisse and Bray and Andrews on the grounds of inaccuracy. On the contrary, admitting that parts are lost through fermentation, a considerable amount of cellulose forms into oxycellulose and pectin on decomposition which, through further oxidation stages, is transformed into humin and ultimately into coal simultaneously with the lignin. Marcusson further claims that an enrichment of lignin does not occur. The characteristic high methoxyl content of rotting wood is derived from pectin and the high alkali solubility from oxycellulose.

[47] Marcusson, J., Lignin and Oxycellulose Theory. *Zeitschrift Angew. Chem.*, *39*, 898–900 (1926).

He repeated the experiment of Rose and Lisse on pine wood. For the determination of cellulose the chlorination method after Cross and Bevan[48] was employed, and for the determination of lignin the concentrated hydrochloric acid method after Willstatter-Krull.[49] The values for cellulose thus obtained checked closely those of Rose and Lisse: 58, 47, 23, and 6 per cent for sound, slightly rotten, semi-rotten, and completely rotten wood, respectively. The lignin values were 25, 32, 44, and 37 per cent respectively, but Marcusson found that the humins in the rotten wood were removed simultaneously with the lignin, so that the values obtained were too high. In order to correct this the humins were first removed from the rotten wood with alkalies after which the lignin was determined. The values now were 23, 20, 23.6, and 20 per cent, respectively, all four samples now containing approximately the same amount of lignin. Further, Marcusson claims that the humin obtained indirectly gave erroneous results. He contends that on account of the asceptic nature of the humic acids no bacteria can exist in peat, hence no biochemical changes and reactions can take place.

Bergius' Theory

Bergius[50] gives both cellulose and lignin equal prominence in the theory of coal formation. His theory rests on two fundamental principles: One that biological processes have no essential part in coal formation; the other that the various and most different plant contributants are transformed essentially into one and the same coal substance. The reaction bringing about this result ranges over a tremendously long time at relatively low temperatures.

Assuming these two fundamental principles as the basis Bergius endeavors to imitate coal formation in the laboratory. He further reasons that reactions carried out over a long period at a low temperature have the same end results as reactions carried out over a short time at a relatively high temperature. This temperature he calculated to be approximately 340°C. Heated at such a temperature, in the presence of water, he obtains from cellulose as well as from lignin an end product closely resembling coal. This coal con-

[48] Cross, C. F., and Bevan, E. J., *Cellulose*, 1901, London.

[49] Krull, H., Dissertation, Danzig Versuche über Verzuckerung der Zellulose. After J. Marcusson. Lignin und Oxycellulose Theorie. *Zeitschrift Angew. Chem.*, *39*, 898–900 (1926).

[50] Bergius, Friederich, Beiträge zur Theorie der Kohlenentstelung. *Naturwissenschaften*, *16*, 1–11 (1928).

sists of alpha coal soluble in alcohol and NaOH solutions, and beta coal insoluble in these solvents. Lignin yields 50 per cent of each, while cellulose yields 70 per cent alpha coal and 30 per cent of beta coal.

THE COMPOSITION OF PEAT AS FOUND BY ANALYSIS AND SEPARATION

The composition and nature of peat so far has been concluded mainly from theoretical considerations and from observed facts pieced together. The question naturally arises, how far do these conclusions coincide with the actual conditions in the deposit?

Attempts have been made to answer this by analyses of peat with respect to its major constituents, such as water-, ether-, and alcohol-soluble matters, humins, lignin, cellulose, and insoluble matters such as cutin, spore, and pollen coats and mineral matter.

The peat from a well-selected wooded peat swamp was analyzed from top to bottom. This offered at the same time differences in time and types of peat, as it must have taken a considerable period to form a deposit about 10 feet in depth, passing through various phases and types of swamp formation, each with its specific flora.

The data are given in Tables VII and VIII from which curves given in Figures 34 to 40 were drawn, presenting the percentages graphically. Two methods of procedure were employed; the one adopted from various investigators and referred to as the chlorine-dioxide method, and the other according to Oden[51] and referred to as Oden's method in the tables and curves.

From these data some general conclusions may be drawn: The different floras prevailing successively during the course of the deposition of the deposit caused specific different types of peat to be laid down in successive layers. These are reflected in the curves as fluctuations. Some layers have resisted decomposition and maceration more than others; certain mosses and resinous woods offered the greatest resistance.

As a whole there is a gradual decrease in the lignin content, a decided decrease in the cellulose content from as much as 40 to 45 per cent at the top to mere traces or none at the bottom, and a general increase in alkali-soluble matter or humins. Therefore, a constant humification of plant materials has been going on in the deposit as time advanced.

[51] Oden, Sven, Einige Torfanalysen im Lichte neuzeitliche Theorien der Kohlenbildung. *Brennstoff-Chemie*, *7*, 165 (1926).

Hydrogen-ion concentration determinations by means of the potentiometer showed that all the bogs tested were acid, ranging from pH 3.18 to 5.8. In those deposits with a clay bottom the deposits

TABLE VII

ANALYSIS OF PEAT BY THE CHLORINE DIOXIDE METHOD, PER CENT

DEPTH	WATER-SOLUBLE		ETHER SOLUBLE (FATS, WAXES AND RESINS)	CHLORINE DIOXIDE + 3 PER CENT SODIUM SULPHATE (LIGNIN AND PENTOSANS)	SODIUM HYDRATE (HUMIC MATTER)	SCHWEIZERS (CELLULOSE)	INSOLUBLE (SPORES AND CUTICLES)
	Cold (simple carbohydrates and nitrogenous compounds)	Hot (starches, gums, organic nitrogen and amines)					
inches	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
3	9.59	12.85	1.8	36.50	9.9	24.97	4.1
6	5.07	9.02	3.77	21.30	15.15	38.85	8.46
9	6.60	8.30	3.83	18.12	14.60	38.81	12.93
12	4.00	11.27	5.28	11.50	17.30	33.02	12.77
15	5.90	6.07					
18	3.50	11.20	3.56	33.4	14.67	22.33	9.46
21	5.08	10.50	3.45	41.3	15.53	14.46	10.41
24	8.82	4.73	1.39	22.3	32.10	7.35	23.71
30	4.05	2.77	1.34	29.6	18.00	9.58	30.54
36	6.05	3.05	8.57	21.3	33.2	9.21	18.30
42	4.50	5.80	7.25	16.4	35.4	2.50	13.56
48	3.18	5.27	4.66	27.7	38.54	6.85	14.36
54	3.60	8.60	2.96	20.3	35.78	5.01	19.52
60	3.45	6.70	2.92	20.16	31.02	20.39	15.36
66	1.78	3.71	2.53	12.61	36.58	23.03	19.21
72	4.78	3.60	4.28	28.81	37.71	7.24	23.71
78	3.88	3.91	1.66	30.2	31.12	10.12	20.19
84	2.55	3.34	3.47	23.95	38.6	4.03	24.05
90	2.27	2.7	1.84	19.43	35.91	2.17	
96	6.21		5.67	20.15	42.86	0.88	21.50
102	5.93	3.44	4.12	18.28	47.96	0.43	23.35
108	3.65	9.05	1.53	15.75	49.50	1.03	18.26
114	10.7	6.3	2.21	18.25	47.8		19.36
120	9.8	7.5	4.45	10.00	51.05		20.40

became more acid from top to bottom; in those bogs where the bottom was marl the reverse was true.

Since microörganisms are found at all depths of a deposit it must be concluded that they are to a large extent the cause of this change. Whether chemical changes independent of the microörganisms are

TABLE VIII

ANALYSIS OF PEAT BY ODEN'S METHOD, PER CENT

DEPTH	ETHER-SOLUBLE (FATS, WAXES AND RESINS)	H_2SO_3 (LIGNIN)	AMMONIUM HYDRATE (HUMIC MATTER)	SCHWEIZER'S (CELLULOSE) CUPRIC AMMONIUM	INSOLUBLE (SPORES AND CUTICLES)
inches	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
3	2.89	42.3	7.01	44.73	2.0
6	3.01	27.3	19.62	38.51	10.62
9	3.22	23.6	21.83	37.15	15.23
12	4.13	21.7	22.84	40.53	12.07
15	2.95	52.6	12.2	23.3	9.03
18	2.80	43.4	25.02	11.27	18.31
21	3.88	34.8	30.84	9.03	21.05
24	2.88	38.3	39.16	11.63	18.53
30	2.80	16.7	43.93	7.18	
36	5.96				
42	4.2	20.32	45.87	5.01	23.35
48	3.68	15.12	53.2	3.58	25.20
54	2.69	17.52	51.78	18.23	9.37
60	1.95	10.28	56.38	22.08	10.82
66	2.2	18.63	50.21	10.36	15.64
72	2.1	11.7	43.98		20.18
78	0.84	17.56	50.2	4.83	10.36
84	1.51	34.20	47.29	1.08	15.30
90	1.67	21.81	54.6	2.01	20.35
96	3.17	17.36	59.8	00.00	18.43
102	0.61		53.7	0.00	21.06
108	3.5	16.28	65.80	2.16	23.46
114	4.2	13.06	60.28		26.32
120	6.6	15.20	61.03	0.00	28.35

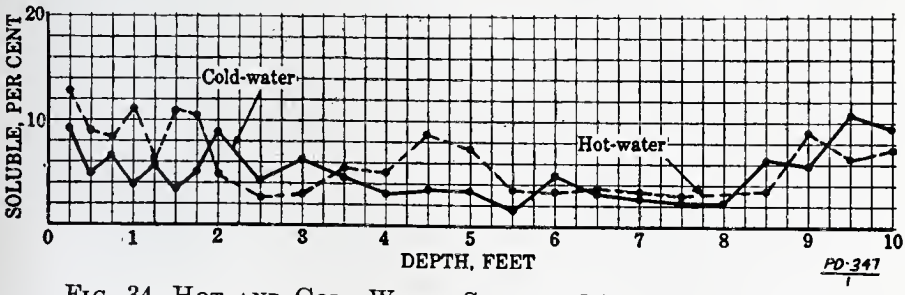


FIG. 34. HOT AND COLD WATER-SOLUBLE MATERIAL IN PEAT

taking place is not known, but it is conceivable that such changes are possible.

Waksman and Stevens[52] obtained concordant results in a similar work. The results bring out that the chemical processes involved

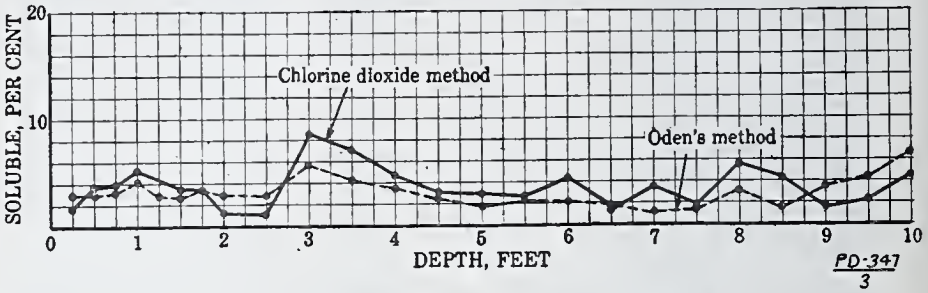


FIG. 35. ETHER-SOLUBLE MATERIAL IN PEAT

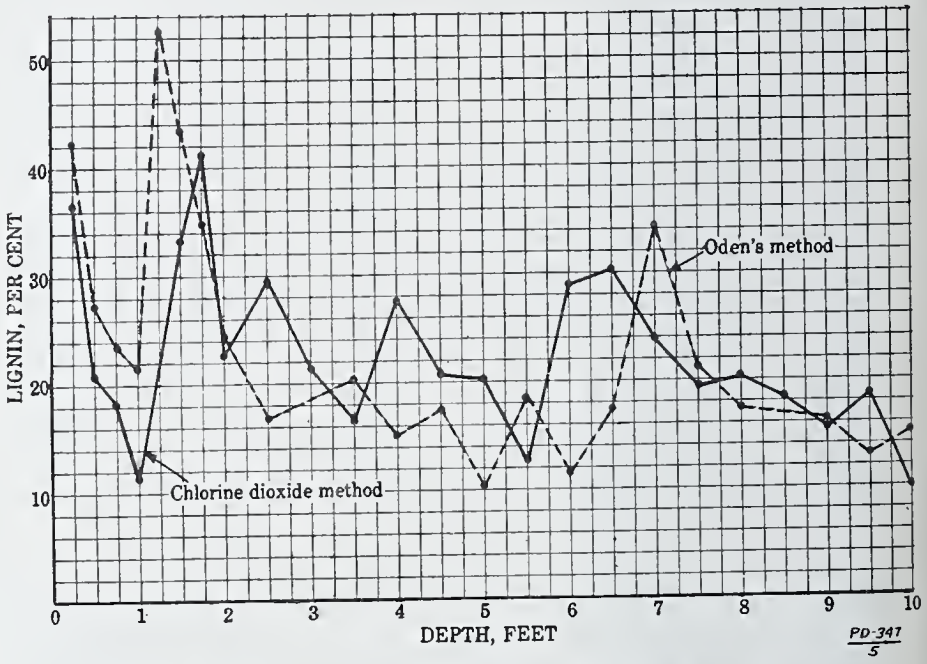


FIG. 36. LIGNIN CONTENT OF PEAT IN RELATION TO DEPTH

in peat are not the same in different peats. The processes in the low moors are summarized as follows: (1) rapid decomposition of the

[52] Waksman, S. A., and Stevens, K. R., Contributions to the Chemical Composition of Peat: I—Chemical Nature of Organic Complexes in Peat and Methods of Analysis. *Soil Science, 24,* 113–127 (1928). II—Chemical Composition of Various Peat Profiles. *Soil Science, 24,* 239–251 (1928).

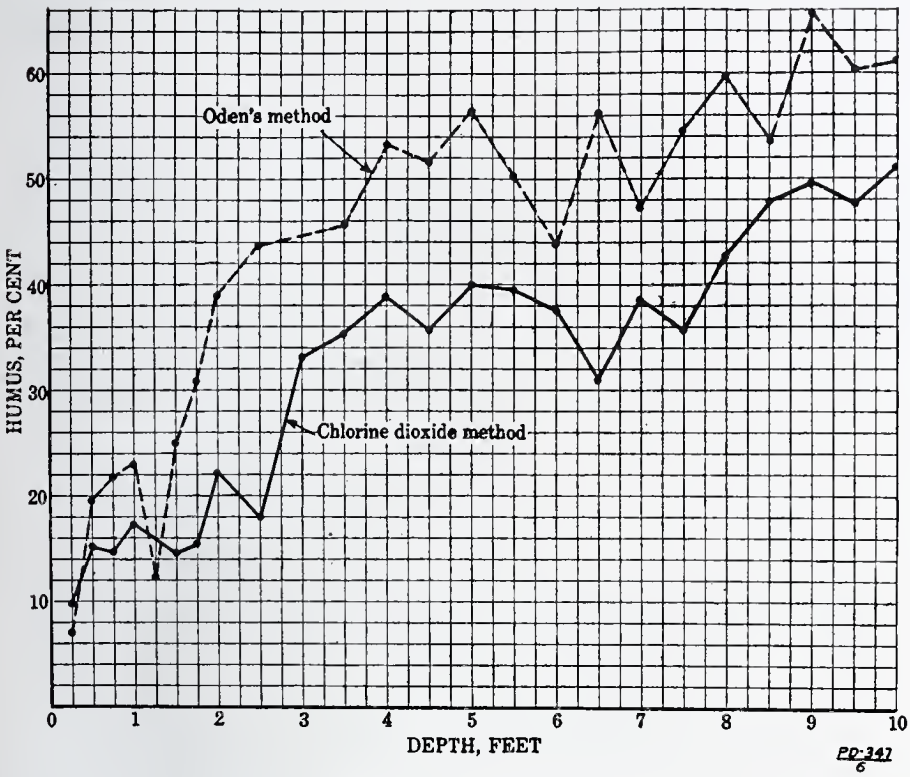


FIG. 37. HUMIC MATTER IN PEAT IN RELATION TO DEPTH

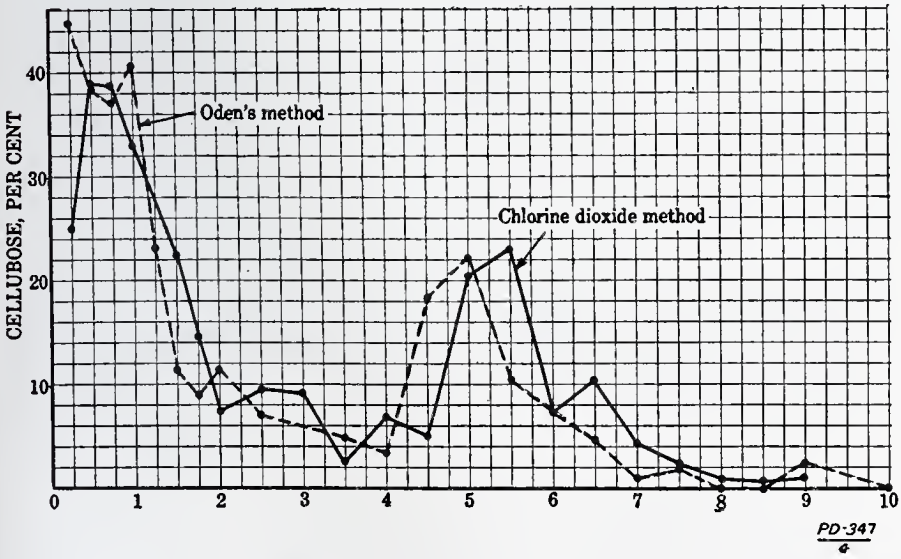


FIG 38. CELLULOSE CONTENT OF PEAT IN RELATION TO DEPTH

water-soluble substances; (2) comparatively rapid decomposition of the pentosans and cellulose; (3) resistance of lignins to decomposition

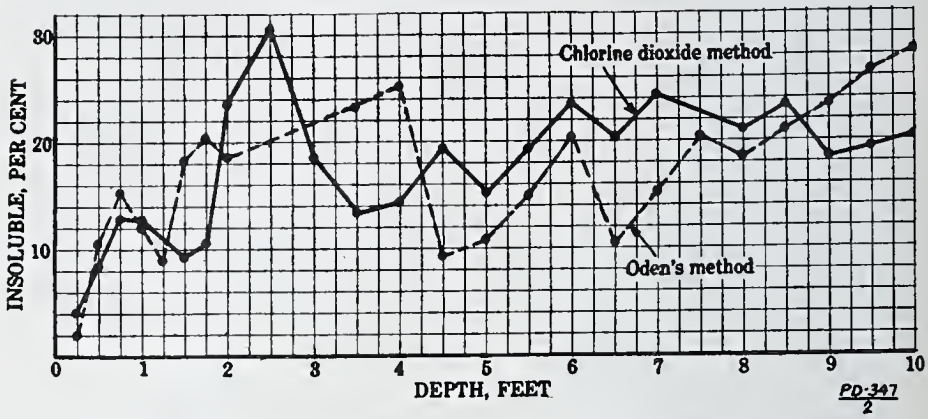


FIG. 39. INSOLUBLE MATERIAL IN PEAT IN RELATION TO DEPTH

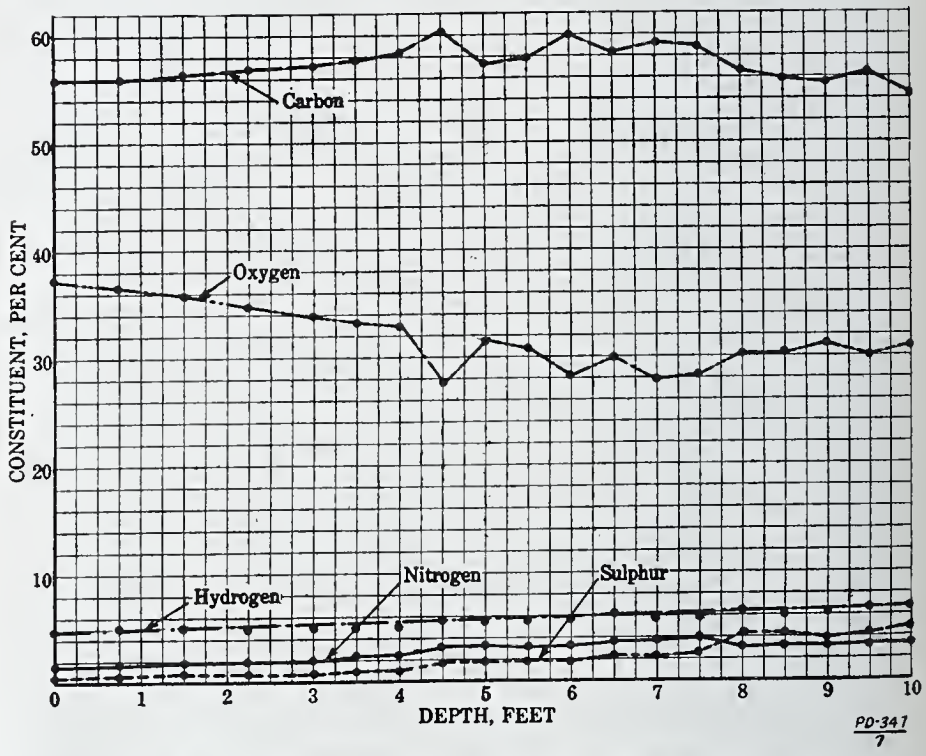


FIG. 40. CONSTITUENTS OF PEAT IN RELATION TO DEPTH

and their rapid accumulation; (4) decomposition of the plant proteins and synthesis of microbial cell substance, finally leading to an accumulation of organic nitrogenous complexes resistant to rapid de-

composition, especially under anaerobic conditions; (5) the persistence of certain hemicelluloses; (6) rapid decomposition of oils, fats, and certain ether-soluble constituents and slow decomposition of the waxes and resins; (7) drainage of the bog brings about an abundant development of aerobic actinomyces and bacteria.

In the high moor peats of which Sphagnum is an important contributant, rich in resistant hemi-celluloses, the processes are as follows: (1) a rapid decomposition of a considerable part of the nitrogenous substances of the plants; (2) a slow decomposition of the carbohydrates of the plants; (3) because the microörganisms have not sufficiently readily available sources of energy the nitrogen of the decomposing Sphagnum is used immediately by the newly growing plants, this accounting for the fact that the peat has no more, and even less, nitrogen than the original plant; (4) slow decomposition and slow, but gradual accumulation of the lignins and the waxy substances; (5) persistence of the celluloses and hemi-celluloses for a considerably longer period of time than in case of the lowland peats.

DISCUSSION

S. A. WAKSMAN (Rutgers University, New Brunswick, N. J.): Although I come to this conference with a point of view entirely different from that of the gentlemen who have presented the papers dealing with the origin of coal, and although I know little about coal itself, I would like to discuss the problem of decomposition of organic matter in nature, a problem which seems to have quite an important bearing upon the origin of coal.

We heard this afternoon, as well as this morning, a great deal about humic substances, humic matters, humins and humic acids, etc. However, nothing has been said concerning the origin of these substances in nature from the plant residues. We certainly cannot imagine that the formation of these organic compounds, if they exist at all, is taking place at 340°C., because the primary and most important changes in the decomposition of natural organic material takes place in an entirely different manner. We cannot speak of the origin of coal from the humic bodies before we know what these bodies are. Why speak of humins and humic bodies when we know that the existence of these in nature is still highly problematical?

The logical question is to ask first, how have these substances been formed? Place a piece of wood, straw, grass or any particle of fresh undecomposed plant material in a peat bog or in soil and examine carefully what is going to happen to the organic constituents of this fresh material under natural conditions. You do not need hundreds of millions of years to observe marked changes, you will see them within a few weeks. The undecomposed plant material consists of definite organic complexes, including water soluble substances, fats, waxes, hemicelluloses, celluloses, lignins, proteins and numerous other compounds. In other words, the fresh plant material consists of definite organic complexes, of a known chemical composition.

If you follow the transformation of these various constituents, when the plant material undergoes decomposition by microörganisms, either in the soil or in the peat bog, you will obtain a very clear picture of the nature of the substances formed and of the nature of peat. There is no use of confusing these products with the terms "humic bodies" and "humic acids," which mean very little in terms of definite organic complexes.

What does happen under the natural conditions of decomposition of organic matter? The chemist sometimes forgets that under natural conditions decomposition is carried out by bacteria and other living organisms. These carry out their activities at temperatures of 15°, 25° or 30°C. The processes of transformation are quite distinct as you can readily assure yourselves by a very simple experiment.

You will recall the theory of the origin of coal presented by Dr. Fischer and associates a few years ago, that all the organic constituents of plant residues, with the exception of the lignins and the waxes, are rapidly decomposed by microörganisms, while the lignins and waxes are left and gradually transformed into peat and finally coal. That is almost correct, but not quite. It is correct to the extent that lignins resist decomposition under natural conditions. However, if you will ask the farmer whether the addition of a certain amount of plant residues to the soil will be sufficient to keep up the supply of organic matter in the soil, he will tell you that he has considerable difficulties in doing that and that there is greater decomposition of the organic matter in the soil than he can very well take care of, unless very large quantities of organic residues are added to the soil every year.

The fact is that the lignins can be decomposed under certain conditions. On the other hand, when you examine the chemical composition of peat, you will find not more than 25 to 50 per cent lignin. You will find 15 to 20 per cent cellulose (in highmoor peats), 10 to 15 per cent hemicellulose in both highmoor and lowmoor peats. You will also find 20 to 25 per cent protein in lowmoor peats and 5 to 10 per cent in highmoor peats. You might ask where such a large amount of protein originated.

Somebody just said that peat is a very homogeneous substance. It is far from it, as the analysis just presented indicates. Lowmoor and highmoor peats are distinctly different in their chemical composition. You must not treat your peat with alkalies and obtain dark bodies, for which you will devise various names, such as "humins" and "humic acids," but you must attempt to analyze the organic complexes in peat and compare them with the similar complexes in the fresh plant material and you will find why certain substances are present in peat and others have disappeared.

In the lowmoor peats made up of grasses, sedges, and reeds, the fungi and the bacteria decompose the cellulose rapidly and build up substances which are rich in proteins and certain hemicelluloses. The celluloses become practically all decomposed. Waxes will not accumulate under these conditions. The lignins are resistant to decomposition under the anaerobic conditions and will accumulate.

In the highmoor peats, where the acidity is high, pH 3.6 to 4.0, and the plants are more resistant to decomposition, you will find an accumulation of celluloses, waxes and hemicellulose, rather than of proteins.

Consider only the decomposition of wood, where the action of different organisms will involve different chemical processes. It has been shown, that certain fungi will decompose the different celluloses, so that a product may result which will contain 75 per cent lignin and only 2 or 3 per cent cellulose. On the other hand, other fungi can decompose the lignins as well and a product is formed richer in celluloses than in lignins. The formation of coal only takes place much later, not of the fresh undecomposed plant materials, but after these materials have undergone thorough decomposition by microorganisms. To understand the origin of coal, we must study these processes of decomposition first. We must also know the chemistry of the plant materials which have undergone decomposition. We must know the organisms that bring about the processes of decomposition. We must know the chemistry of these processes. Only after we have this information, shall we be able to speculate on the chemistry of the coal and the processes of its formation.

DR. D. WHITE, (United States Geological Survey, Washington, D. C.): I am glad to hear the result of such mature and progressive research as we have heard today. We shall hear more as the problems are more clearly defined and are grappled with broader vision as well as with better training and technique.

Much of the success of this work is primarily due to superior technique. Probably the backwardness in understanding coal from the microscopical standpoint in Germany is due to their deficient technique. Otherwise, some of the literature that is now appearing under high auspices in that country would be impossible.

Mr. Lebeau speaks of an anthracite lignite. I do not know what he means, whether it is a Tertiary or a Cretaceous coal, whieh most people in Europe still call lignite, that has been brought to an anthracite stage on a regional scale, or whether it is a contact metamorphism phase of a lignite. This should be clearly stated before his analytical data can be properly oriented.

In any study of the carbonization of coal it is necessary to distinguish between the metamorphism that is local and of the contact type, and that which is regional. Granting that the reactions may run parallel in both cases, it is very important in the study of the evolution of the deposit from peat to anthracite that the coals be fully described in every instance and that the conditions and causes, so far as known, of their carbonization be always a part of the picture presented by the research worker. The term pyro-anthracite seems to need explanation or even justification, as the case may be. I assume that the term is applied only to anthracite which is the result of contact metamorphism.

The paper presented contains the suggestion of high temperatures in the process of anthracitization. If we are to follow the dictum of Dana—if we are to interpret the geological conditions and events of the past in the light of procesess which may be observed and of products resulting therefrom in the present—how shall we view any proposal which predicates high temperatures in areas where the coal has reached only a rank like that of the coal near Pittsburgh or of the coking coal in Cambria County, or of even the anthracite of the eastern regions?

Judged by the most careful measurements made in America by Dr. Van Orstrand of the Geological Survey, the temperature gradient as we go down to a depth of 7,000 feet will be around 1 degree to 80 or 90 feet of depth in the Appalachian region. This slow downward increase may be attributed to the fact that this region has long been quiescent and has been subjected to no great compressive stresses incident to diastrophic revolution since the post-Paleozoic revolution, or perhaps the post-Triassic structural movements.

If, however, we go to the Rocky Mountain areas where great stresses have been exerted in post-Cretaceous time, we find the temperature gradient of the basins falling in general near 60 or 65 to the degree Fahrenheit.

In California, where mountain building is not only most recent but still in progress, Pleistocene beds being folded in some areas, we find geothermal gradients steepening to as high as 25 or even 20 feet to one degree of increase in temperature. This is probably near the maximum temperature of purely deformational origin in exposed beds in the region.

Taking a 20-foot California rate as a maximum representing a region of active stress, we will have to go down about 1,000 feet to gain 40°F. in temperature, or 6,000 feet, if the gradient does not considerably steepen, as it probably does, to get an increase of 240°. A great depth would be required to reach 450°.

The building in which we are meeting is not far from the level of the Pittsburgh coal bed, which is the basal member of the Monongahela formation. There is nearly 300 feet of Monongahela above us and 1,300 feet of Dunkard or Permian above that. It is hard to conceive that in this broad basin there could ever have been more than 1,800 or 2,000 feet of strata above the Pittsburgh bed. Sediments in a thickness of 1,000 feet may have been removed from the top of the Dunkard, but it is hardly possible that 2,000 feet of strata have disappeared. Are we ready to admit a necessity for having 6,000 feet of beds above the Pittsburgh coal at Pittsburgh, Connellsville, or Ocean in Maryland in order to bring the coal to a standard coking or even to a higher rank? Had there been 6,000 feet of beds above where we now stand the temperature, at the California rate, might have been somewhat over 250°F. at this level. At that, however, we would still be very far short of the temperatures of fusing points of bituminous coals as reported by Parr, or those at which we pass from the endothermic to the exothermic reactions.

Meanwhile, we should not lose sight of the time element. Some investigators are giving attention to it experimentally; so should we.

Pyro-anthracite cannot, I think, stand in terminology. Speaking of terminology, let me insist that we should aim at scientific forms as well as precision of nomenclature as stressed by Dr. Thiessen. I dislike, however, to see an apostle of purism in nomenclature, as he aspires to be, use the words "coal ball." Those "balls" are not always balls and they are not coal. They are roundish concretions; but they are not and never will be coal balls. That point was settled at an extremely early stage in their career. They are nodular masses of petrification Some term other than that improperly given them by the British coal miner, who found the knobby masses in the coal beds, should be used. "Coal balls" should not be tolerated, much less perpetuated, in scientific nomenclature.

With reference to some of the "constituents" of coal, may I point out that clairain and durain, not to mention vitrain, present physical distinctions, but, properly speaking, they are never ingredients of the coal as they were originally described to be. They owe their characteristics to conditions of deposition more than to differences in the ingredient matter from which the coal was formed. These so-called constituents are not distinctive ingredients of coal and they lack definite distinctive chemical characteristics. The chemistry of the original matter in each changes with every turnover in the progress of the coal from rank to rank until it reaches anthracite or graphite.

I cannot view durain exactly as Dr. Thiessen does at the present moment, though I should like to. It is my impression that the coals he has used for comparison in America are possibly slightly under the carbonization rank of the British coals which he cites as so different from the American in respect to durain. Perhaps he should compare Cambria County coals instead of the lower rank coals of the vicinity of Pittsburgh and of most of our bituminous coal fields. Durain-rich British coals appear to retain products of the last stages of the decomposition of the organic debris as also do some of the coals of ordinary rank in America. Greater opacity in the British specimens may be due to the exact point of their carbonization, a point not represented by the American specimens that Dr. Thiessen has happened to study.

The structure of the European coals, in which Dr. Thiessen shows the material to have been jumbled, may well be the result of shearing of the coal; that is, its slow and slight deformation under horizontal stress. The illustration of the Ruhr coal exhibited by Dr. Thiessen seems to indicate a degree of schistosity, such as is readily accounted for by the tectonic history of the region. Dr. Thiessen has brought out very plainly the fact that there is no inherent distinction of origin in the coal, in which the physical difference shown by the aspect of the specimen is apparent. A reasonable and, I believe, most probable explanation of the schistosity is found in the effects of a second period of diastrophic stress endured by the coal after it has already progressed somewhat in rank. Such structure as shearing effects in coal already formed, though not necessarily of its present rank, is to be expected where, as in western Europe, Paleozoic coals long before subjected to the horizontal compressive stresses of the post-Paleozoic revolution were later forced to endure the effects of late Mesozoic or post-Mesozoic deformation. The Appalachian and Mid-Continent coal fields in America have been relatively free from buckling and stress since the post-Paleozoic revolution. Their coals have not endured further crushing stresses exerted on preëxisting folds.

The term fusain deserves retention and general adoption. It is greatly preferable to "mineral charcoal," a term that suggests a questionable explanation, or "mother of coal," which it is not. I should like to ask Dr. Thiessen, since I think there is room for debate as to the origin of fusain, how prevalently he finds genuine charcoal in peat bogs of the very humid regions of America.

DR. R. THIESSEN (United States Bureau of Mines, Pittsburgh, Pa.): In the last two years my assistant, Mr. Johnson, and I have made some very interesting discoveries with respect to the origin of fusain. We found a considerable amount of fusain-like material in the lower strata of a peat deposit, where fire is out of the question.

Recently, Dr. Grund has come to the conclusion that fusain is formed in the peat stage and the problem of the origin and cause of fusain must be worked out in the peat stage. In our discovery we can verify this. As already stated, in one of the peat bogs, at a depth of about 10 feet, we came across a layer of reed peat containing stocks and leaves of reeds and herbs in an advanced stage of carbonization. This matter is very much blacker than the rest of the peat. If these same inclusions were found in the lignites, brown coals, or sub-bituminous coals, they would at once be called fusain.

Here is a definite inclusion formed through a fermentation process and not through fires. That same peat deposit has near the surface a thin layer of peat which contains real charcoal.

About 63 to 66 years ago, during the Civil War, this area of the bog was cut down for cedar posts. That part of the swamp is now overgrown with a second growth, the largest trees of which are about 10 inches in diameter. At the depth of a foot and a half, we came across this layer of charcoal. This layer is of interest for two reasons—first, it shows, since it is real charcoal, the difference between charcoal formed through fire and the more highly carbonized matter found farther below; secondly, it shows the relative amount of peat formed during the last 63 to 66 years.

DR. J. B. SHOHAN (United States Bureau of Mines, Pittsburgh, Pa.): I should like to add to the statement made by Dr. Waksman in regard to the function of the chemist in coal research; I too am interested in organic chemistry.

There is no doubt that the study of the chemical nature of coal has been largely neglected. Professor W. A. Bone has often deplored the situation saying that "inasmuch as coal is a complex colloidal organic substance, of high molecular aggregation, the task of elucidating its chemical constitution should be intrusted to the organic chemist" and that "we would do well to import more organic chemists into our fuel laboratories, and to rely more and more upon the systematic methods of organic chemical research."

It seems to me that the state of coal research today is somewhat the same as that of organic chemistry in the middle of the last century. At that time great interest was shown in the physical structure of matter, and undoubtedly many valuable by-products, as for example the fruitful field of stereochemistry, were thus obtained. On the whole, however, the relative importance of crystallography in the study of the constitution of organic substances decreased as a deeper insight, due to the marvelous development of structural organic chemistry, became possible.

In view of this, an undue emphasis on the visible differences among the constituents of the coal substance is not justified, and the organic chemist who seeks to elucidate the problem of the chemical constitution of coal need not consider seriously the admonition of Stopes, who says: "Indeed I am not too bold to maintain that until a recognition of the differing essential compounds forming the coal mass [fusain, durain, clarain, vitrain] is the foundation for the chemical worker's investigation of coal, the chemistry of coal will remain in the Dark Ages." Subsequent work has shown, on the contrary, that the "differing essential compounds," separated by the naked eye, differ only in

degree and that they avail the chemist but little; for obviously any useful division of the coal conglomerate must be into groups of compounds of distinctly different kind.

In the paper under discussion, the use of other terms, such as "attritus," "anthraxylon," and "resin" is urged because these appear to be easily differentiated microscopically; and considerable evidence in support of these views has been adduced. I wonder, however, of how much value this separation is to the research chemist who attempts to resolve the heterogeneous and complex coal material into chemically different substances and to determine their structure. It is possible that the controversy over naming substances which we can as yet define only with the eye may obscure the need for increased chemical research conducted along the lines of modern organic chemistry.

The methods which have proved so eminently successful in investigating other complex natural substances must be applied to coal. A good start has already been made in that direction, but only in much further diligent pursuit can the problem eventually be solved.

DR. THIESSEN: I would like to answer that in a few words. We are fully aware that coal and humins are very complex substances. We have known it all along. But, in order to make a beginning we have to name certain constituents in order to convey the identity of such constituents to the other fellow so that he may know about what one is talking.

We are at the beginning of things. We are beginning at the bottom and are gradually working up. Some day—although we may not live to see that day—we will know the whole process of the transformation of the plant substance into peat and the transformations of peat into coal, and will know much more about coal than we do now. I am quite sure of that. But we need organic chemists of a high caliber in order to be successful to that end.

One of Dr. Fischer's men, Dr. Tropsch, believes that we are not able to solve the true nature of the constituents of peat with the present knowledge of organic chemistry. We have to acquire further knowledge in organic chemistry, and I believe he is right.

AN INTERNAL COMBUSTION ENGINE USING PULVERIZED COAL

By Rudolph Pawlikowski

General Manager, Kosmos Maschinenbauanstalt, Görlitz, Germany

The Engine Works Kosmos in Görlitz, Germany, since 1911 have maintained a research laboratory for the purpose of creating a serviceable coal dust motor. The tests failed on small size engines. It was not until 1916 that the first reliable coal dust ignitions were obtained with bituminous coal, charcoal, and brown coal on a vertical 4-cycle Diesel engine, rebuilt for this research work. This engine, built in 1906 by the Engine Works Augsburg-Nuremberg, has a bore of $16\frac{1}{2}$ inches, a stroke of 25 inches, and its rated output at 160 r.p.m., when operated on fuel oil, is 80 b.h.p., or at overload about 92 b.h.p. This engine was described in *Power* issue of July 24, 1928, *Engineering* issue of September 28, 1928, and *Journal of the V. D. I.* issue of September 15, 1928. The data given in these publications will be repeated here in part only as far as it is necessary for the understanding of this paper, and will be supplemented by further details and results of recent date.

The most natural arrangement, to add coal dust to the fuel oil, and, after preheating, to atomize this viscous black oil in the present Diesel nozzle, failed. In the first place, the piping of the oil pump clogged up easily, and second, even after proper atomization was obtained, the coal particles in the emulsion burned poorly and in general formed coke. Apparently, the heat of compression was consumed by the latent heat of evaporation of the oil film enveloping the coal particles which does not allow the coal core to be burned completely, within the time available. The problem to be solved, therefore, was one at which perhaps a hundred inventors from all countries had so far worked in vain. Failures in research work are usually kept secret by inventors and manufacturers; only the patent literature gives an indication of the wearisome trails full of expense and disappointment, and leading into the virgin forests of future discovery. The author, during 40 years of work on internal combustion engines and as a former coworker of Dr. Diesel in the development of the Diesel engine, had an opportunity to follow these attempts by information acquired within these years. From such data it seems

that almost every large motor builder in Great Britain, France, Germany, Switzerland, and in a few cases in the United States, independently or in coöperation with inventors, such as Wieckfeld, Beck, Levassor, Rohnstadt, Bernstein, Wolff, Benier, Stallaert, Diesel, Pinther, Maccallum, Worgitsky, Wachtel, Vogt, Trinkler, Sulzer, Holzwarth, Clarke, Weikersheimer, Fuller, Schnuerle, and so on, has tried to produce a serviceable coal dust engine. It would lead too far to explain the character of these previous developments, in order to make clear why the coal dust engine of the Kosmos Company in Görlitz operates reliably. Essential for its success was the fact that the research in Görlitz has been carried on with the funds of the company without any outside capital and could, therefore, be carried through unwaveringly in spite of many disappointments and mistakes. The unbelievable difficulties of the World War, of the post-war period, of the inflation and the long delays in securing patent rights, particularly abroad, have drawn out the development exceedingly, and yet on the other hand, given the opportunity to test every individual step of the work in continuous operation by quiet experimentation over many years. The development of the Diesel engine from 1894 to 1898 was crowned by the sale of licenses, but did not offer a practical design until the engineers Buz and Lauster of the M. A. N. due to their never-tiring tenacity succeeded in meeting the requirements of continuous operation during the following 6 years, until 1904.

The problem of the coal dust motor is the injection of the pulverized material into the cylinder at the end of the compression against a pressure of about 430 pounds per square inch without briquetting and the keeping tight of the admission valves at temperatures in the engine of 2,200° to 3,300°F. and 430 to 700 pounds per square inch pressure. Furthermore, the small amounts of coal dust must be apportioned exactly as to what each stroke requires according to the load of the engine. This amount has then to be burned with certainty during the following working stroke, otherwise, the regulation is poor and the coal dust will smolder, coke, and stick to the metal. There was no way to determine in advance how the ash would behave and how it could be made harmless in the cylinder, because so far nobody had succeeded in obtaining a perfectly controlled combustion of coal dust in continuous operation in engine cylinders.

The new motor introduces the coal dust into the cylinder by an

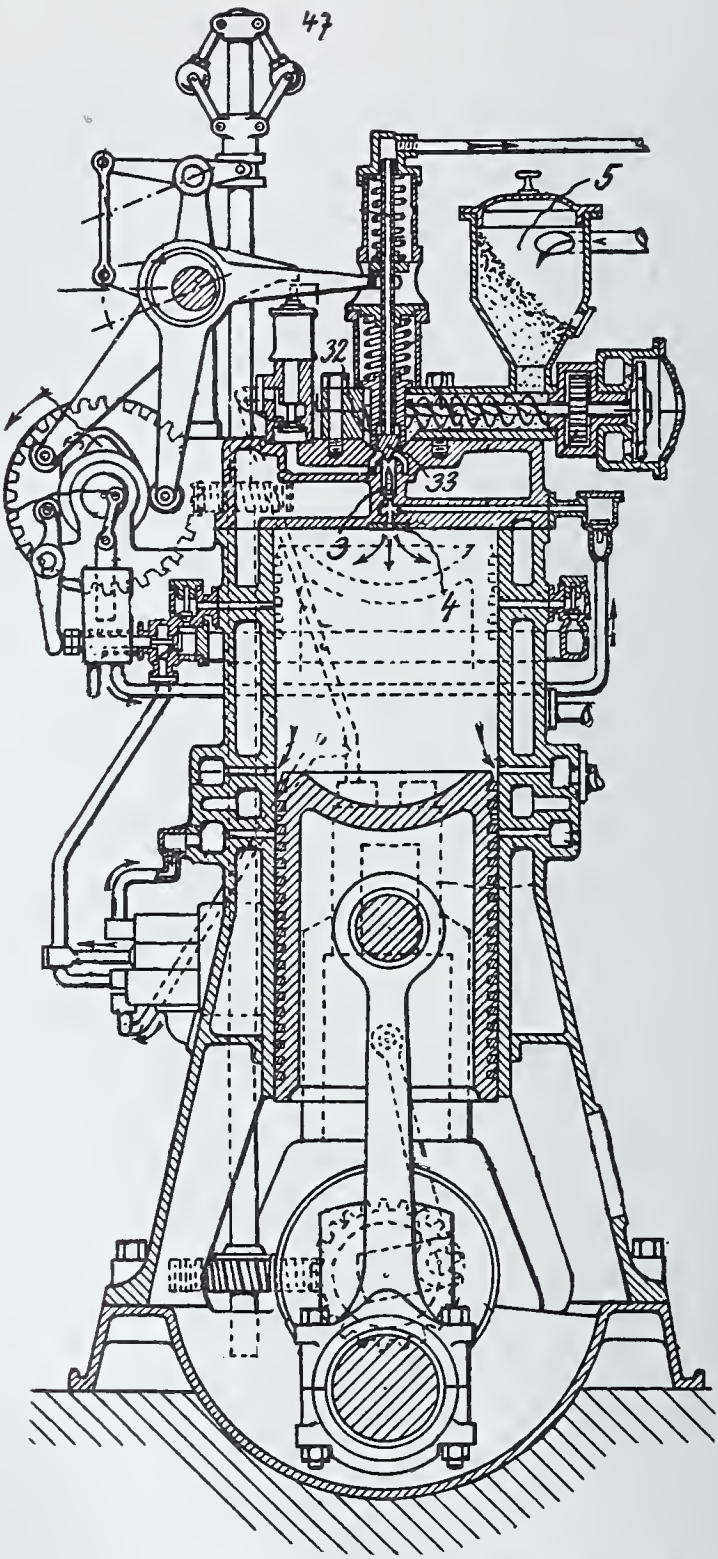


Fig. 1. Longitudinal Section Through Rupamotor

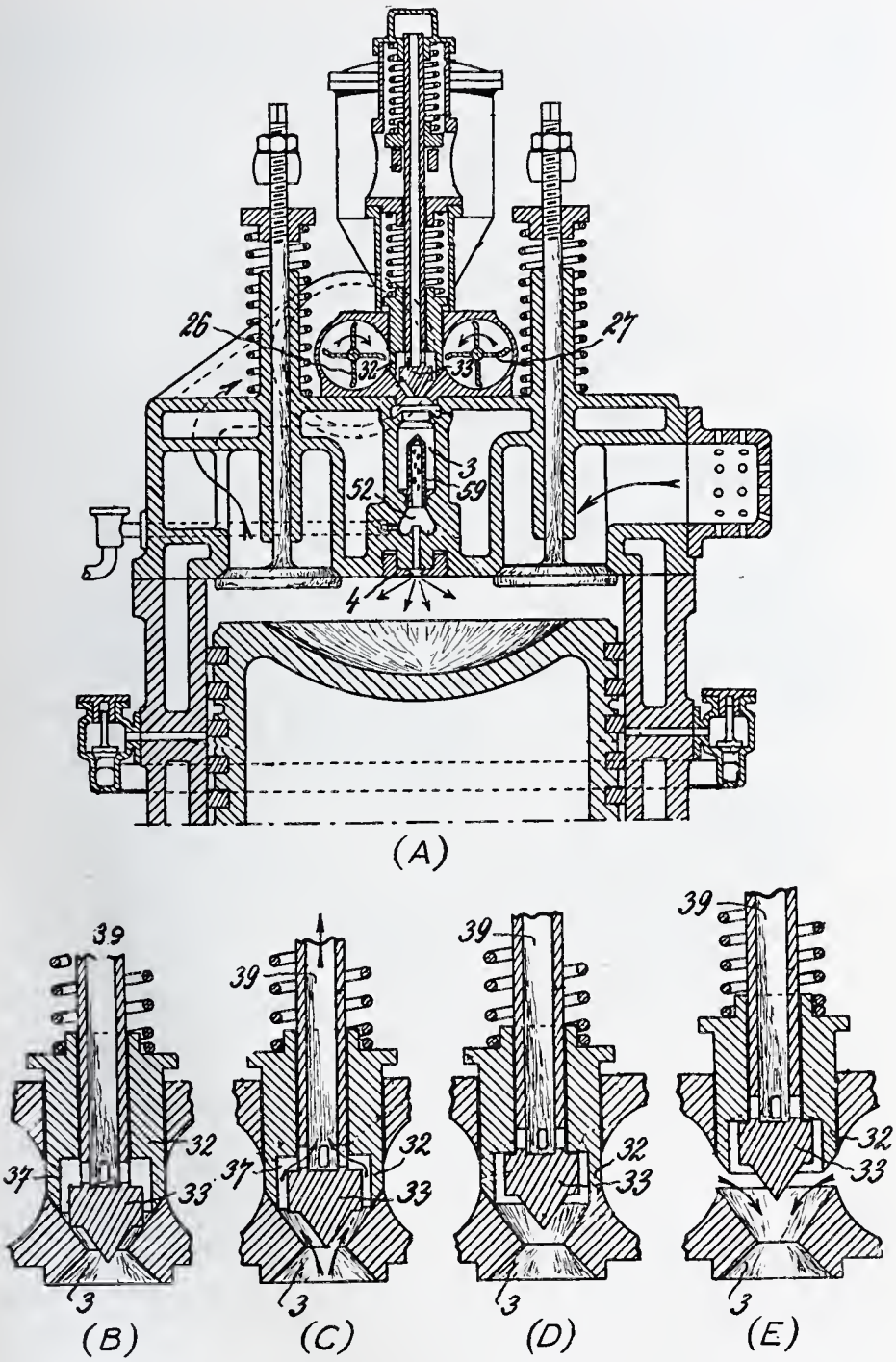


FIG. 2. DETAILS OF CYLINDER HEAD OF RUPAMOTOR

antechamber which works on the principle of a sluice. The coal dust is brought into the chamber at approximately atmospheric pressure, then the chamber is closed, charged with compressed air, and the coal dust is blown out into the cylinder. Finally it must be relieved of the remaining gases and pressure in order that a new

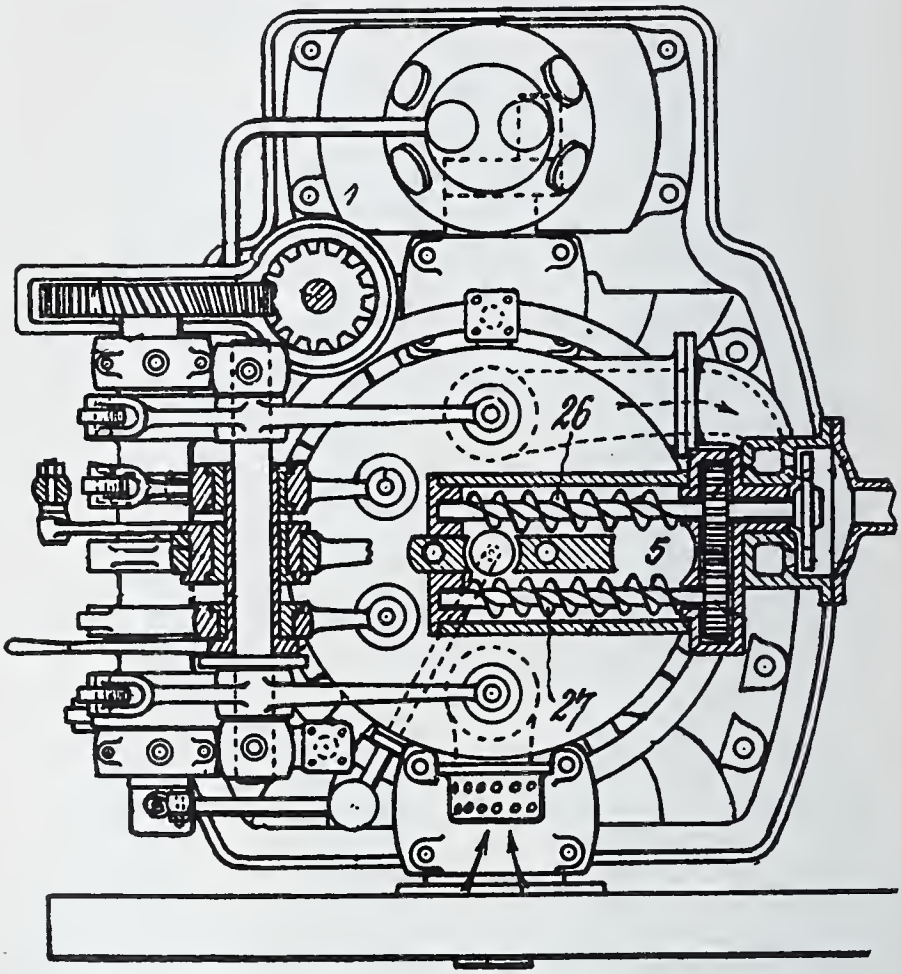


FIG. 3. DETAILS OF CYLINDER HEAD OF RUPAMOTOR

charge of fuel dust can be supplied. The sluice chamber, marked *3*, is shown in Figures 1 and 2. The coal dust is supplied through the supply valve *33* which is surrounded by a second valve *32*, which is a sleeve valve and which controls the amount of coal dust supplied for each stroke. The coal dust is supplied from the container *5* to this double valve by means of two centrifugal worms *26* and *27*.

In passing through the conveyor the coal dust is thoroughly emulsified with a little air and thereby increases its fluidity to such a degree that it can be exactly apportioned when flowing by the controlling edge of the outer valve *32*. The governor *47* controls the sleeve valve by varying magnitude of valve lift and time of lift. Any leakage through the inner supply valve *33* escapes through the open ring space *37* and *39* and does not in any way affect the coal dust which is lying deposited behind the sleeve valve *32*, ready for the next stroke. At first, in 1916 to 1918, the vent of the sluice chamber was closed towards the working cylinder by means of a mechanically operated valve, and very regular ignitions with coal, charcoal, and finally brown coal were obtained. Later on, the sluice chamber was always left open to the cylinder, as is indicated at *4* in Figure 2a and thereby the change of pressure in the working cylinder, which is necessary for the proper functioning of the chamber, was utilized to good advantage. The open sluice chamber is simpler in design and allows on a 4-cycle engine the preheating or preparation for ignition during the whole intake stroke and because the hot compressed air enters this chamber during the entire compression stroke. It has at its lower end a separate space *52* for the deposit of fuel oil and can be operated on oil as well as on coal or on both at the same time. In order to avoid having the coal dust enter prematurely from the chamber into the working cylinder during the suction stroke, the chamber is suitably shaped and is provided with a perforated tube, which at the same time holds back any foreign matter. The extended time interval for the preparation for ignition makes the engine more adaptable to high speed. Since it can be operated without injection air, if suitably designed, this new injection principle may also become important for high speed oil engines. Contrary to the Diesel engine, it compresses air and fuel simultaneously; however, it keeps them separated until the end of compression and until injection. It therefore improves the Diesel process in principle, because in the latter the fuel oil is atomized, heated, and ignited during a small faction of one stroke of the engine, whereas the new motor provides a complete stroke, or 10 or 15 times as long for the same transaction.

The 80 h.p. engine has been operated during the past 12 years, from 1916 until the present time, on powder of bituminous coal from Upper and Lower Silesia and the Rhineland, on brown coal from Germany and Czechoslovakia, on peat from Upper Bavaria, on wood dust, charcoal, rice husks, meal, and even furnace coke not

only for research but also as motive power for the Kosmos Machine Works.

The coal dust must be as fine as that used for firing on boilers and locomotives, and the fineness must grow with the moisture and ash content and with low volatility. Eighty per cent of slowly igniting high ash coal could also be ignited with sufficient rapidity when mixed with 20 per cent lignite.

The engine may be started on coal only or on oil, and can be switched quickly and easily from one to the other fuel during operation. When working on coal, it has developed 120 b.h.p. and quite

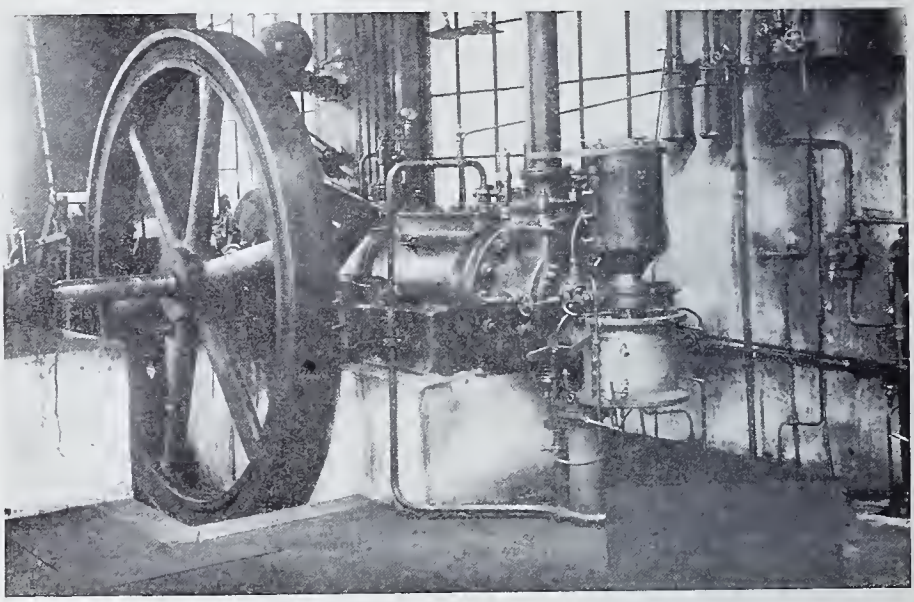


FIG. 4. FIFTY HORSEPOWER RUPAMOTOR

recently, in spite of a wear of $\frac{2}{10}$ inch at the upper end of the cylinder, 110 b.h.p. were developed. This corresponds to 110 pounds per square inch mean effective pressure without supercharging. The maximum obtainable mean indicated pressure on coal as fuel was 160 pounds per square inch with only 51 pounds per square inch at the end of expansion. The heat of coal is therefore converted into work as efficiently as the heat of oil in the Diesel engine. The new engine can work with less excess of air than the Diesel engine, apparently, because the particles of coal, burdened with ash, even though of very fine mesh, penetrate the dense air, compressed to 430

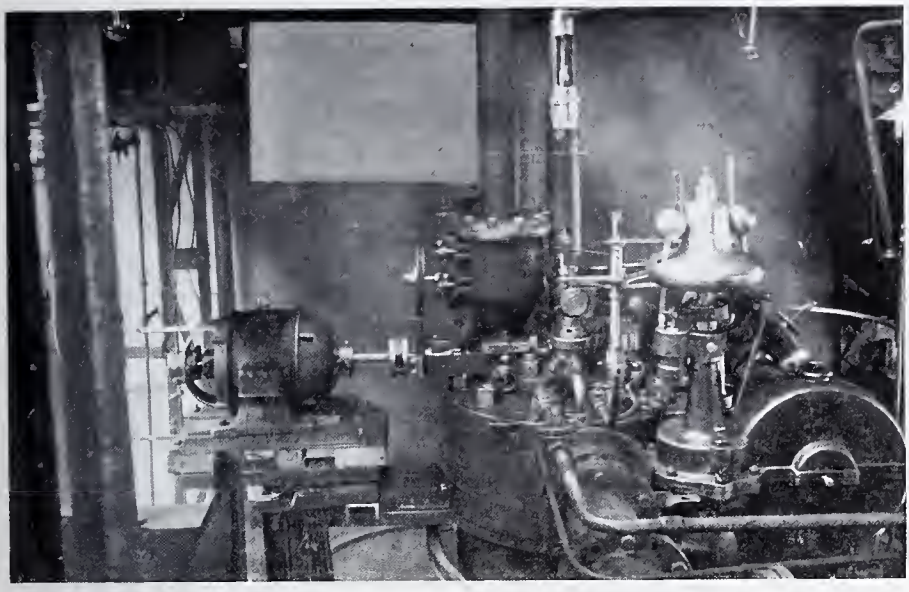


Fig. 5. Early Rupamotor with Conveyor Screw Driven by Electric Motor

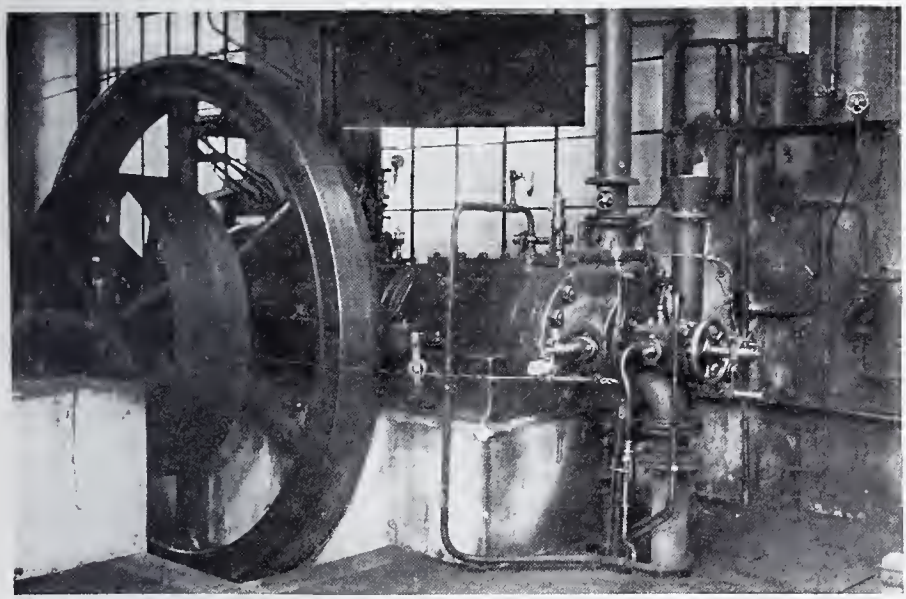


Fig. 6. Fifty Horsepower Rupamotor with Intermittently Moving Conveyor Screw

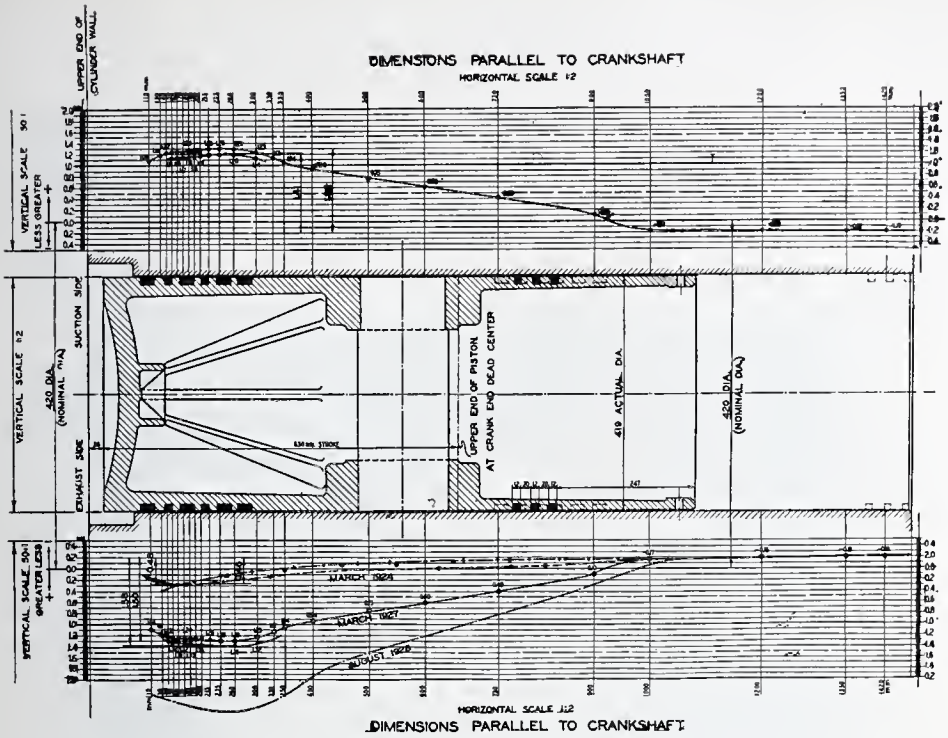
pounds per square inch, with a greater projectile force than the small globules of oil which completely evaporate and separate into molecules.

On a 40 h.p. horizontal, single cylinder, 4-cycle engine of Deutz, with injection air compressor, the conveyor screws, shown in Figure 4 were driven by an exhaust turbine, arranged with a vertical shaft in a cylindrical housing. In this case, the motive power was taken from the engine proper. In the beginning of the research work, the conveyor screws on the 80 h.p. engine were driven by a motor, shown in Figure 5. The exhaust turbine, perhaps the first one in the world operated on coal dust, ran at 6500 r.p.m. continuously and reliably. In spite of this we simplified this engine, shown in Figure 6, in that the auxiliary chamber now consists of a water cooled box only, whose conveyor screws are standing still during regular operation and are only moved by means of a hand wheel shortly before the starting of the engine.

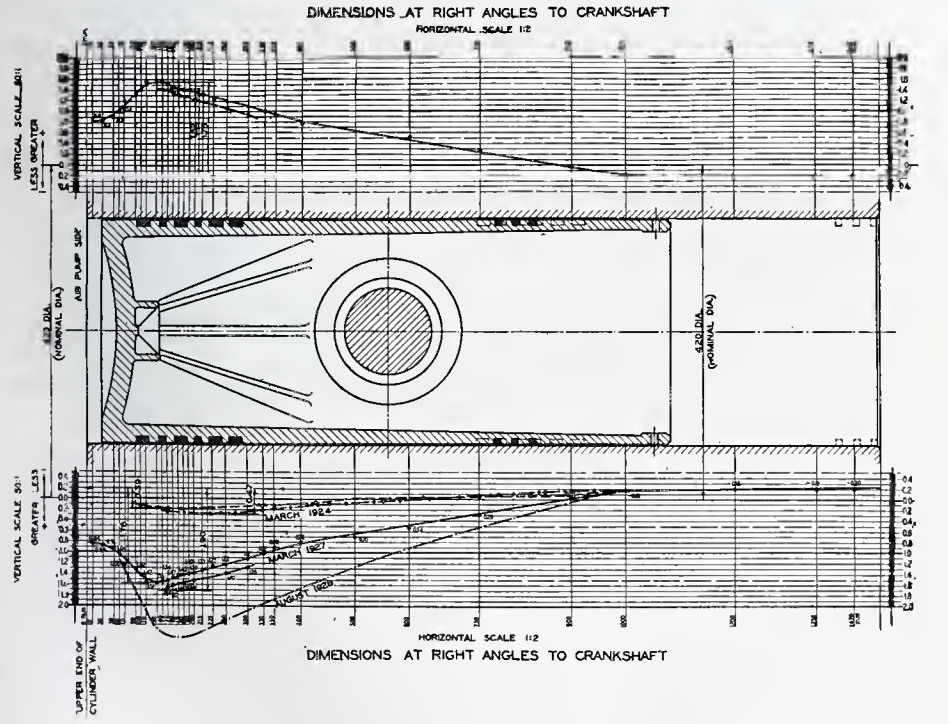
The sluice chamber is termed with the new name "auxiliary chamber" and in contradistinction, the name antechamber is reserved for that separate space of the cylinder through which the fuel oil is ignited more or less near the end of the compression stroke and is thereby atomized in the customary way. On the contrary the new auxiliary chamber holds the fuel charge, already introduced before the beginning of compression, and which can be discharged either by compressed air from an outside source or by excess pressure due to partial ignition at the end of the compression stroke.

Experiments in Görlitz have shown that some grades of coal ignite better and more regularly with auto-injection, but slowly igniting coals make the use of injection air desirable. Therefore, until further development, the coal dust engines of Kosmos will be built so that they can work with injection air from an air compressor or with auto-injection; they can be switched from one method to the other during operation without shutting down the engine. In addition the change from liquid to pulverized fuel is accomplished by means of simple manipulation on all of the engines without interruption of service.

It has already been reported that the 80 h.p. engine can still drive the factory after 9,000 hours of operation on coal dust and that, with the first cylinder liner which has not yet been rebored, with the first piston supplied by the M. A. N. in 1906, and after 12 years of experimentation without having ever seized, it still maintains



A



B

FIGS. 7A AND 7B

a compression pressure of 430 pounds per square inch. It is of interest to study the wear of the liner from the exact measurements. Figures 7a and 7b show the variation in the amount of wear on the cylinder walls throughout the length of the stroke. Figure 7a shows the wear as measured in a plane parallel to the crankshaft and Figure 7b shows the wear as measured in a plane at right angles to the crankshaft.

The measurements were made, to nearest 0.05 mm., by micrometers with reference to a concentrically located shaft accurately turned to 60 mm. diameter. The shaft was centrally adjusted at points 10 mm. from each end of the cylinder when the bores were round to within 0.03 mm. After the very rough treatment during the first years of experimentation, an increase to 421 mm. bore was measured in March, 1924, and the wear extended only over one-third of the stroke downward from the combustion space. The original bore of the cylinder was *419 mm.* or 1 mm. smaller than the nominal size of the engine. From 1924 to March, 1927, there was an additional wear of 1 mm. (0.04 inch), increasing the bore to 423 mm. From March, 1927, to August, 1928, the wear was another millimeter all around, or about the same amount as that of the three preceding years, increasing the bore to 425 mm. This shows that the wear in the beginning is much slower than later on which is due to the fact that in a worn cylinder the piston rings, on the downward stroke scrape harder with the lower edge on the cylinder wall and cannot be twisted sufficiently to lie flat with the outer circumference against the tulip-shaped cylinder wall. The wear curve has the same shape as the combustion and expansion line on the indicator card. Without doubt, the fire gases enter behind the rings during combustion and expansion and press them hardest against the wall where the pressure in the cylinder combustion space is highest. During the working stroke, the rings lead the piston on its downward stroke and likewise, during the compression stroke the rings are pressed against the lower side of the ring groove of the piston. The work, or friction loss during these rather complicated relative motions of piston rings to cylinder and piston, is consumed not only in wearing off the metal, but to a great extent in pulverizing and grinding to finest powder the relatively small ash particles. They are filtered through the oil films covering the top and bottom faces of the ring grooves of the piston which action increases with the extent of leakage of gases past the rings. Systematic research on these points should be started by

the universities in order to enable the human mind to delve more deeply into the complicated natural processes for the benefit of progress. Research has taught us to so control combustion that the formerly observed accumulation of slack craters, shown in Figure 8, on top of the piston, caused by improper arrangements, is now

Fig. 8. Slag Deposit of Ilse Brown Coal (Powdered) in the 80 hp. Rupamotor

avoided. This picture was taken by removing the exhaust valve and illuminating the piston obliquely by a covered bulb underneath the cylinder head. Similar deposits of slag were never discovered on the wall of the cylinder.

The greatest variety of powdered fuels, their ignition, indicator

cards, effect of flame, and behavior of mineral ash substances were investigated thoroughly with about 500 different designs of auxiliary chambers and thousands of individual tests. We determined the

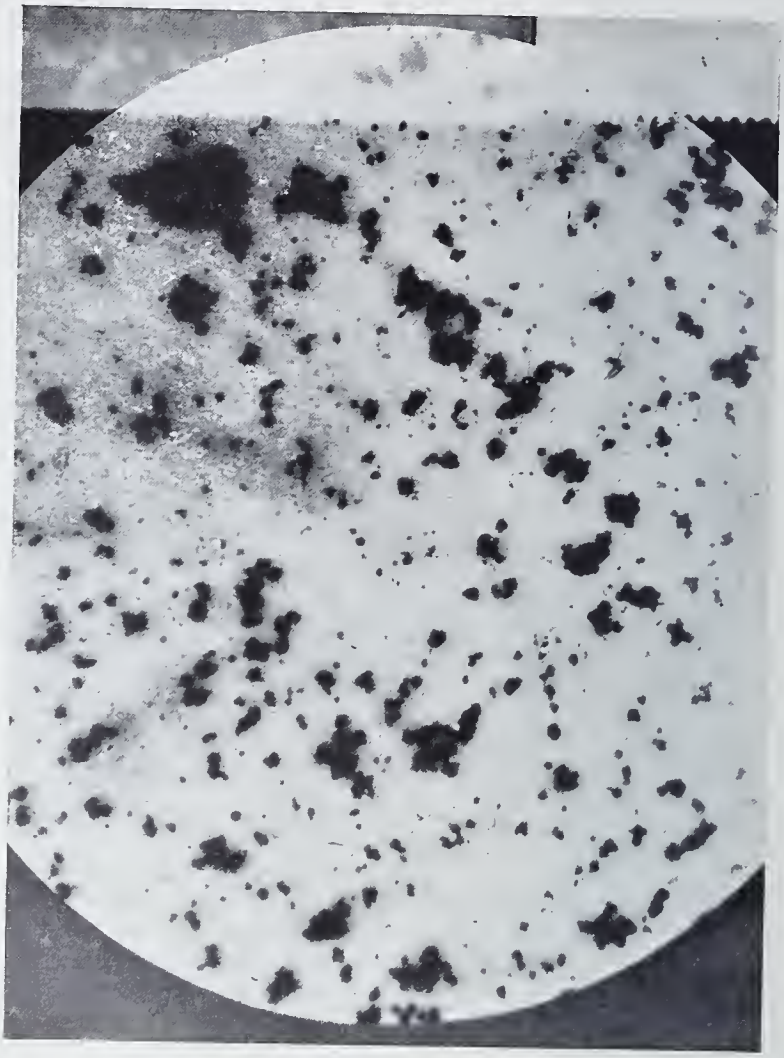


FIG. 9. BROWN COAL ASH FILTERED BY A CLOTH FROM THE EXHAUST FROM THE 80 HP. RUPAMOTOR—MAGNIFIED 200 TIMES

limits which exist between the territory of poor and unreliable operation and that of satisfactory and uninterrupted service in conforming with natural laws. Prof. Dr. Langer, of the Technical College in Aachen, tested the engine in operation at our plant and collected the

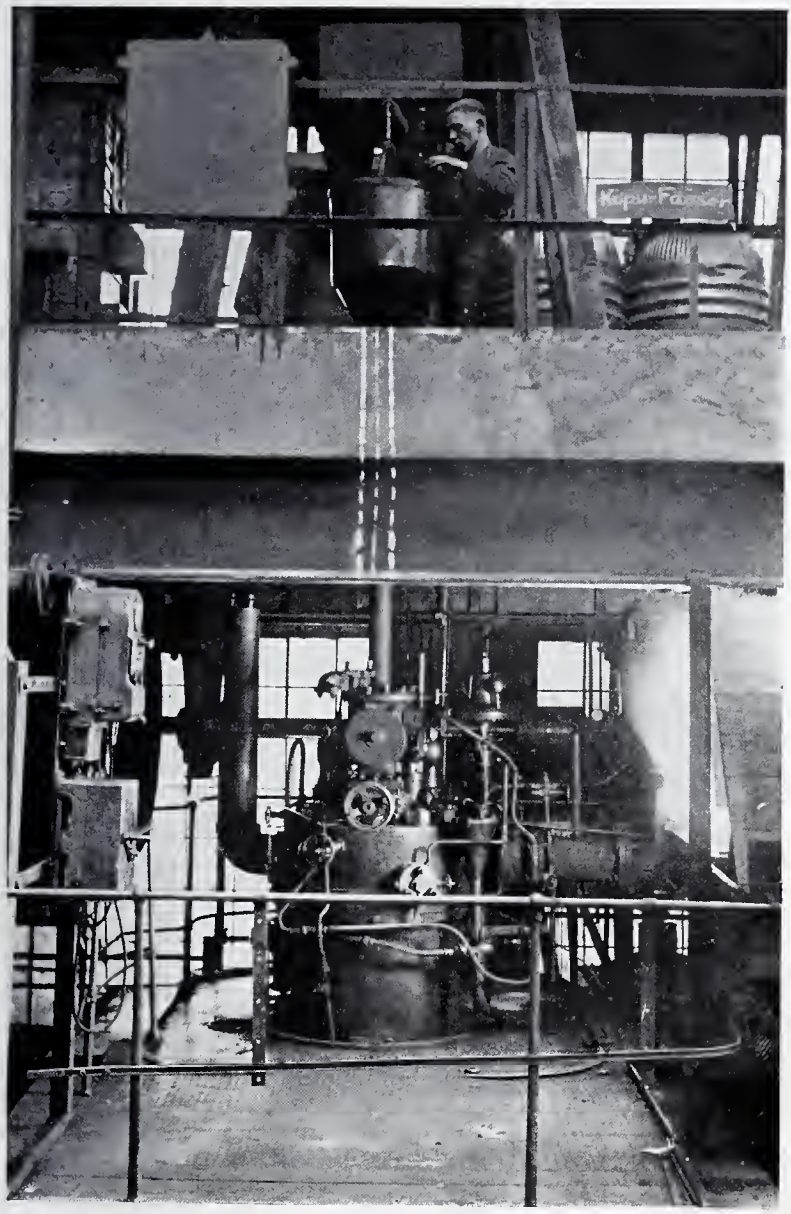


FIG. 10. CYLINDER OF 80 HP. RUPA ENGINE
Note coal dust receptacle and feed pipe

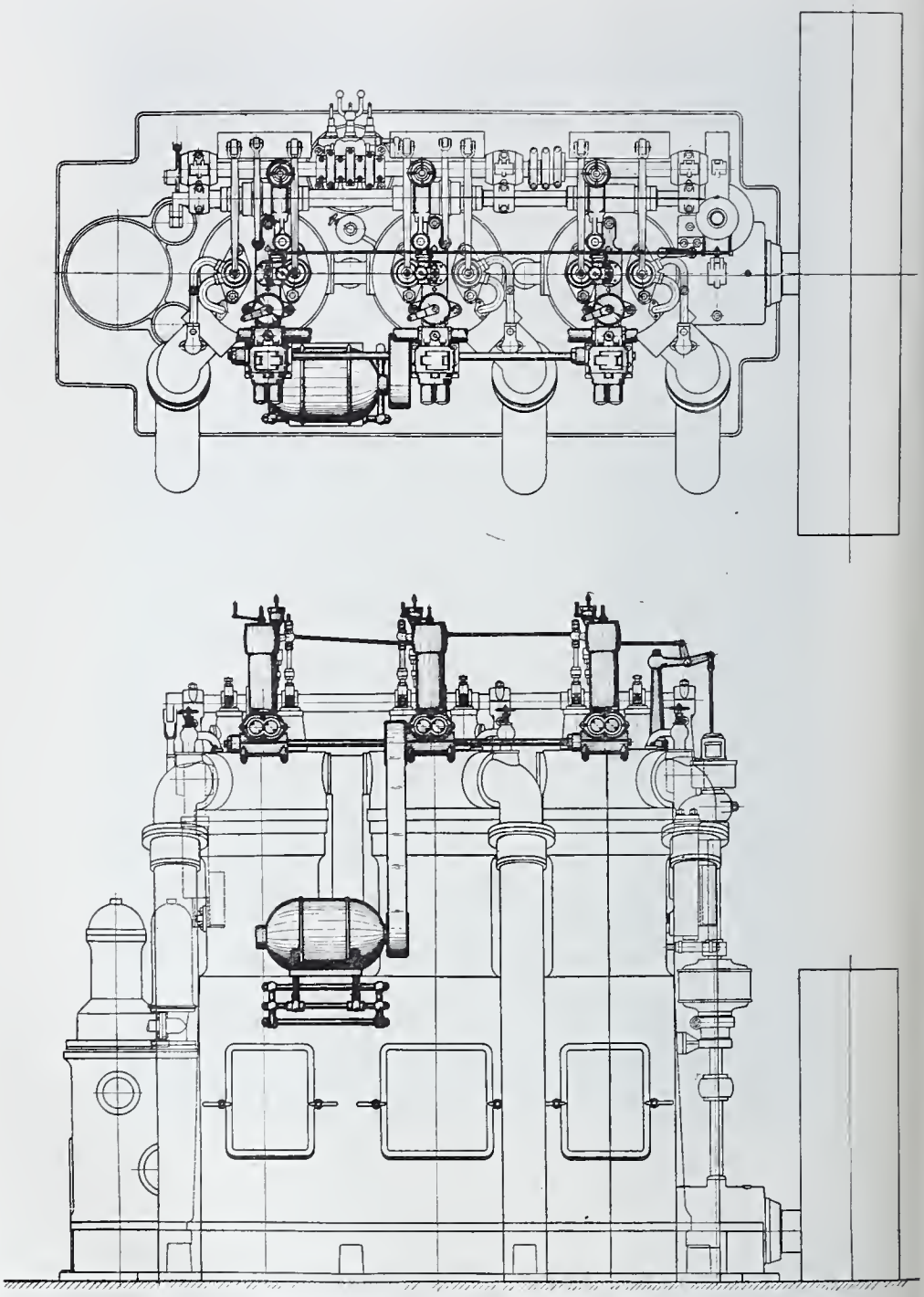
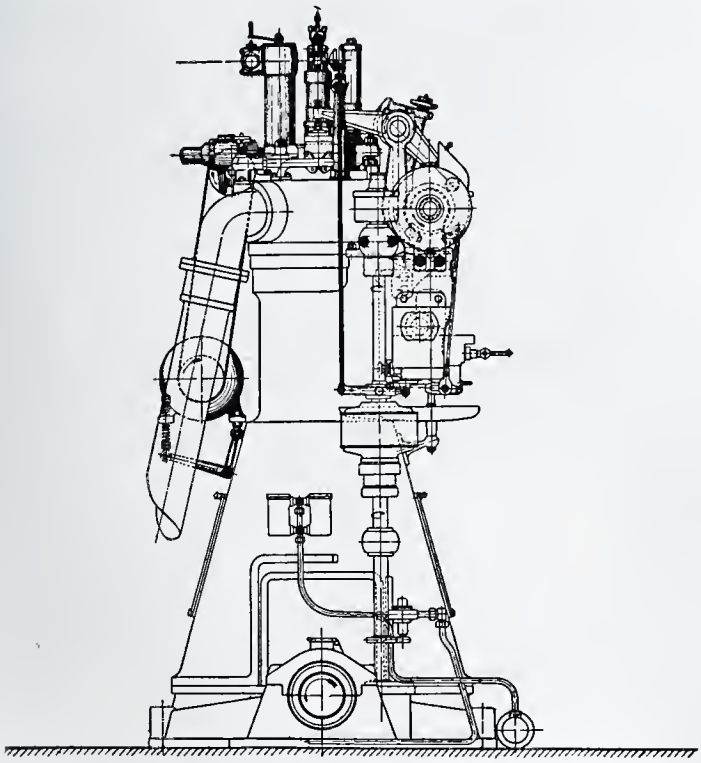


Fig. 11. Conversion of 150 hp. Diesel Engine into a Rupamotor

Heavy lines show new part

ash particles which were large enough to be retained on a filter cloth. The smaller ones passed through the cloth with a light haze; Figure 9 shows the filtered ash particles 200 times magnified. The largest grains measured $\frac{4}{10,000}$ inch in diameter. The ash particles appear as individual bodies without agglomeration and are, therefore, considerably smaller than the original grains of coal dust, and also smaller than the oil film which always exists between piston and cylinder. Therefore, most of these particles which penetrate into the lubricating oil can come in contact with only one side of the two rubbing metal surfaces of cylinder and piston, and probably also between piston rings and cylinder bore. Only relatively large grains of ash, thicker than the oil film, will rub against the walls, but they are soon crushed and ground to finest powder. With an adjustment and arrangement of the parts in the auxiliary chamber suited to the kind of coal in use the exhaust is free from all coal and coke dust and from any tarry or oily matter. Therefore, a 30-foot factory wall situated



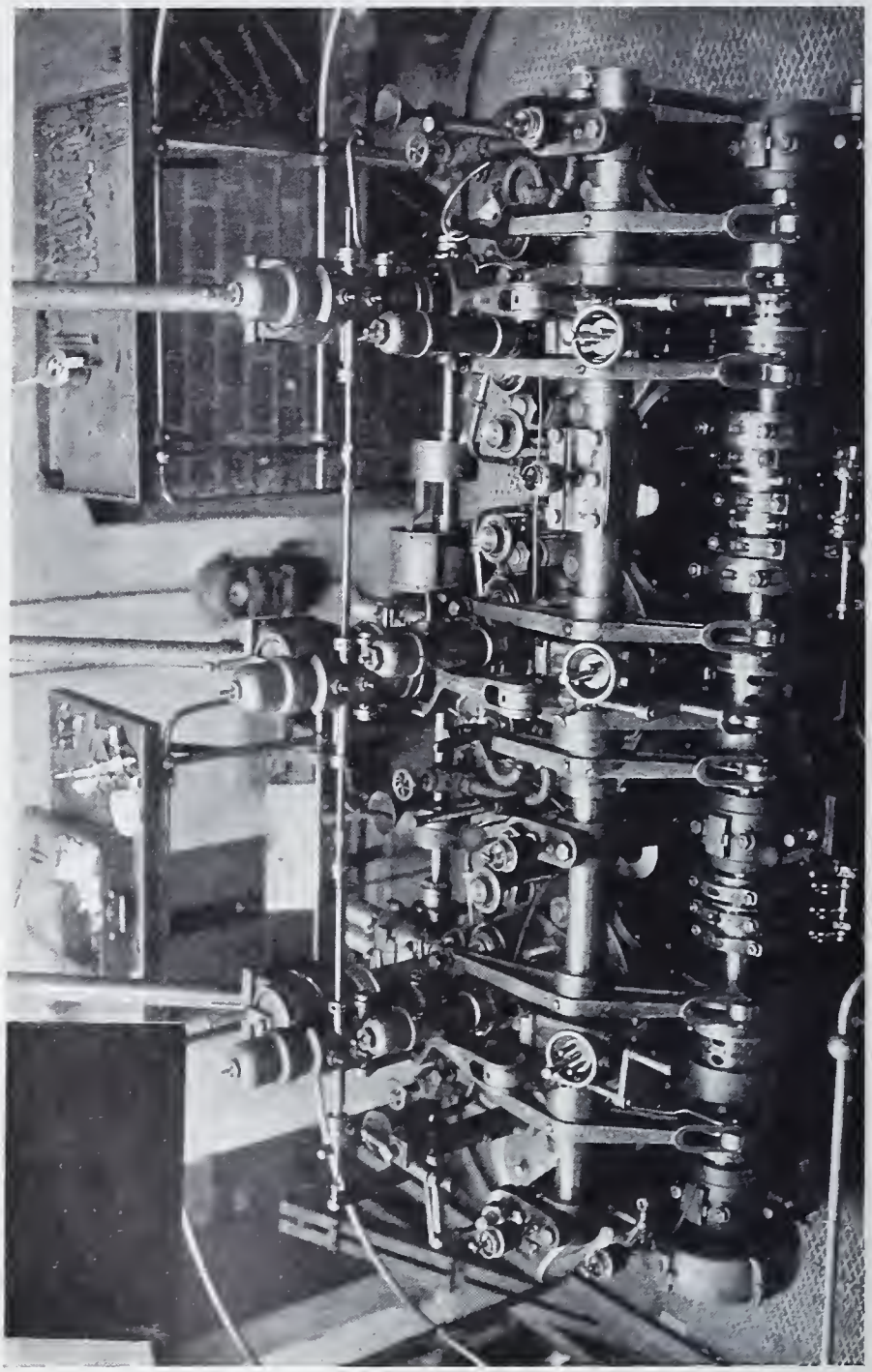


FIG. 12. VALVE GEAR OF RUPAMOTOR SHOWN IN FIGURE 11

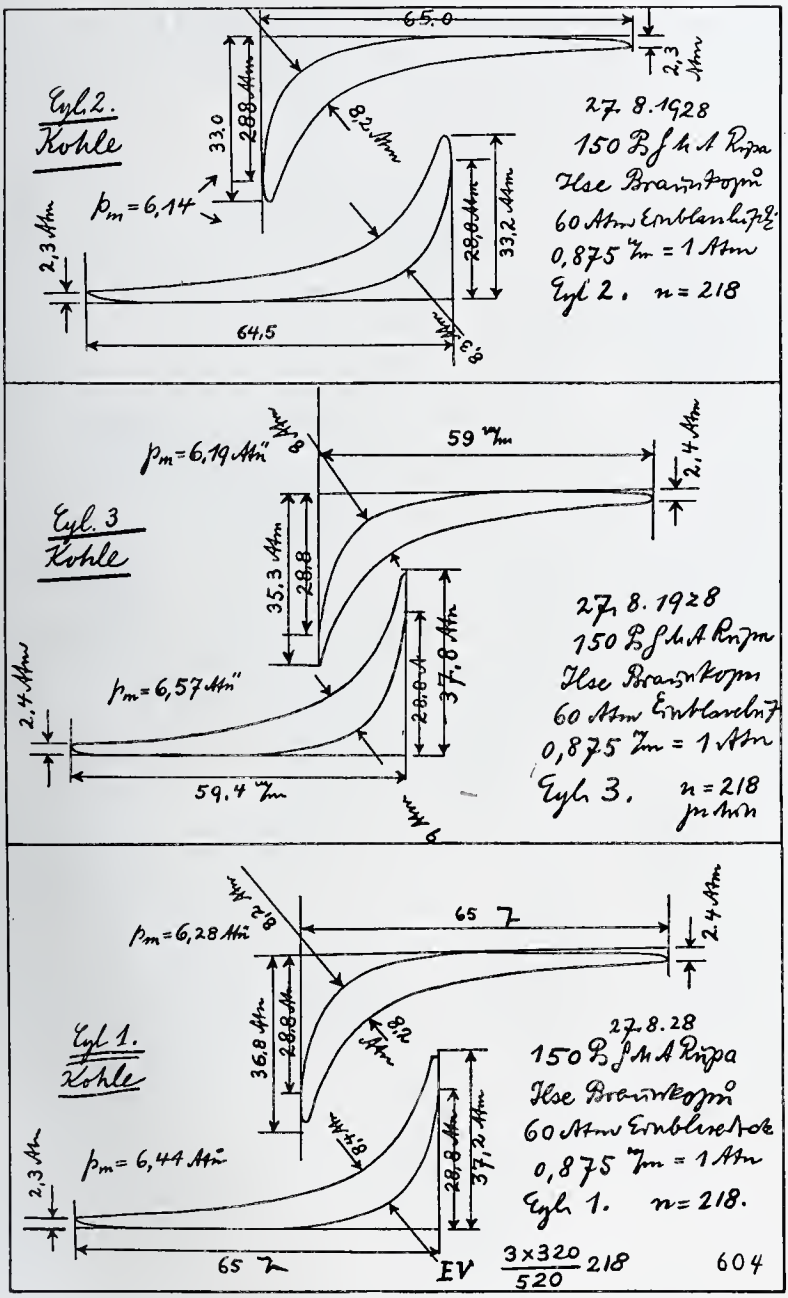


FIG. 13. INDICATOR CARDS TAKEN FROM RUPAMOTOR

Three cylinder—320 mm. diameter—520 mm. stroke—218 r.p.m. On each card 150 h.p. Rupamotor. Ilse brown coal (powdered) 60 atmosphere injection pressure; scale of spring 0.875 mm. = 1 atmosphere.

close to the exhaust of the 80 h.p. engine has remained perfectly clean without any trace of black.

It was also proved that ignition is not started by vapors of lubricating oil, and also that none of the oil forms part of the fuel consumption of 8,135 B.t.u. per brake horsepower equal to 0.91 pound lignite with 10 per cent ash, 11 per cent moisture, and 8930 B.t.u. per pound heating value. This proof was furnished by lubricating the engine for several days with soap water without a drop of oil for piston lubrication. No change whatsoever could be noted in operation of engine, shape of indicator card, etc.

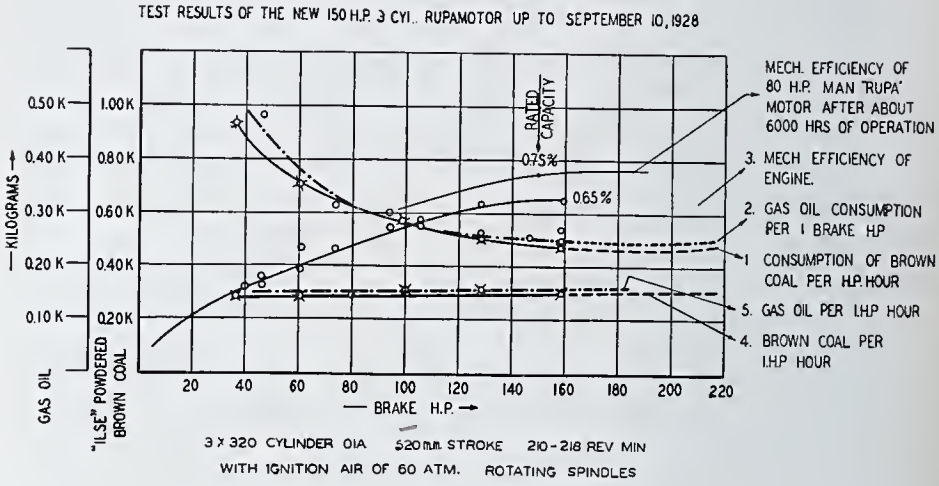


FIG. 14

Figure 10 shows the upper part of the cylinder with platform of the 80 h.p. engine and its coal dust receptacle with stand pipe extended through the ceiling to the floor above.

The word "Rupamotor" was chosen for the new engine as a short trade name and was taken from the two first syllables of the name of the inventor, Rudolf Pawlikowski.

In the meantime, another 3-cylinder Rupamotor of 150 h.p. converted from a standard Diesel engine, has been running at the factory. In Figure 11 and the outer rebuilt parts are marked by heavy lines. Figure 12 is a view of the valve gear from above. Three standpipes, inclined supply pipes, can be seen in the background. They were kept separated in order to measure the coal consumption of each cylinder. For later operation one closed feeder line for all three cylinders, coming from the pulverizer building will

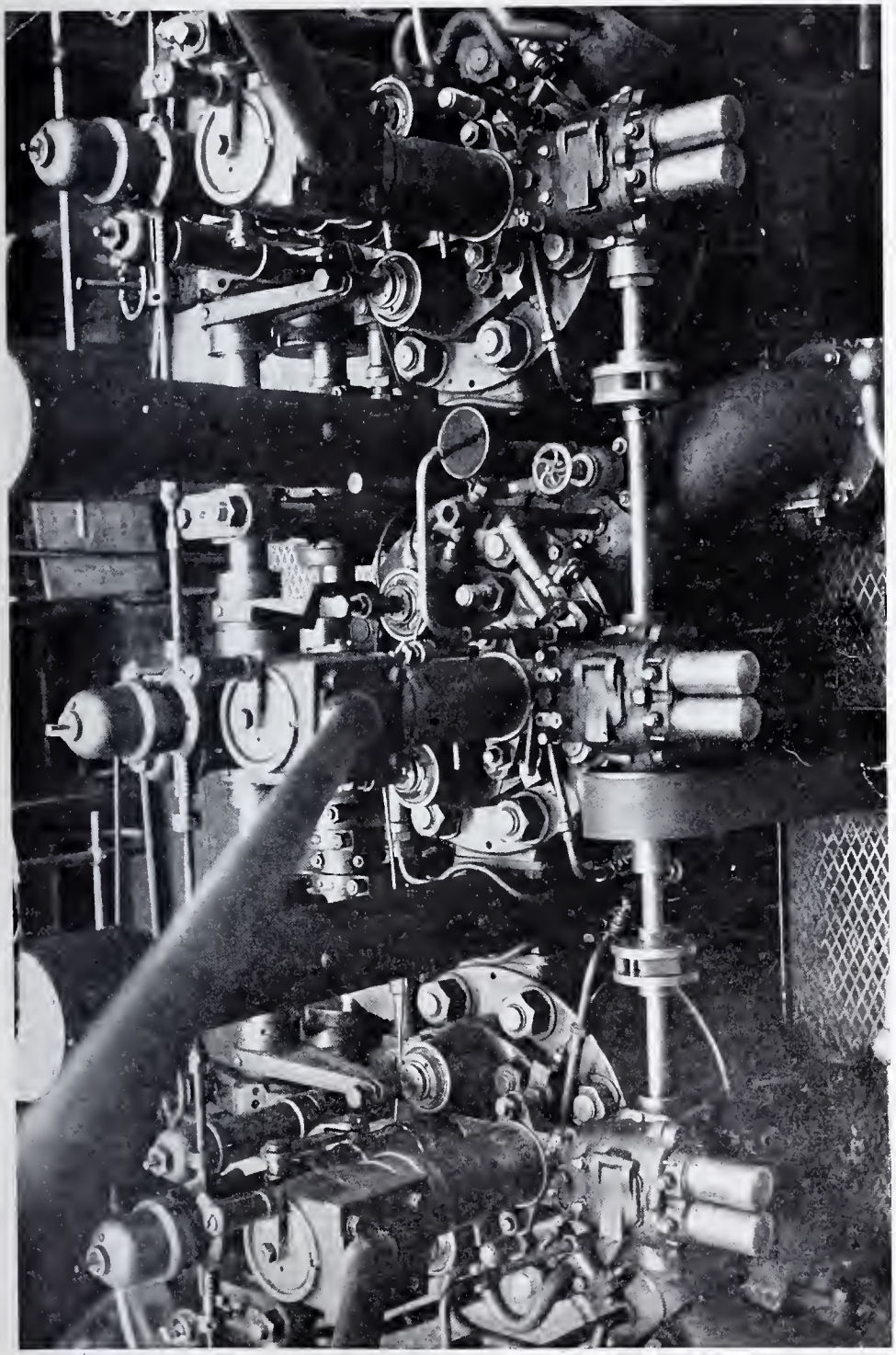


Fig. 15. Improved Valve Gear of 150 hp. Rupamotor

be provided. Figure 13 shows the indicator cards of this engine, operated on pulverized lignite and Figure 14 is a record of the consumption per brake horsepower of a great many brake tests of this engine, operated on brown coal from the Ilse mine near Senftenberg in Central Germany with 10 per cent ash, 11 per cent moisture, and about 9000 B.t.u. per pound heating value. It also contains tests with gas oil from North America with a lower heating value of 18,350 B.t.u. per pound. Up to now the mechanical efficiency of the en-

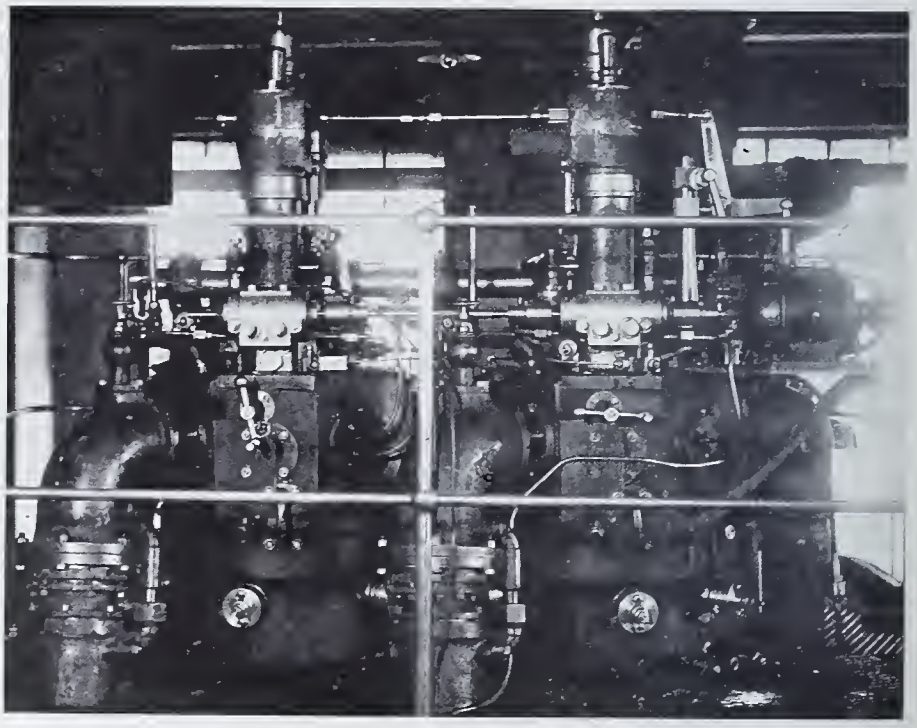


FIG. 16. VALVE GEAR OF TWO CYLINDER 100 HP. RUPAMOTOR

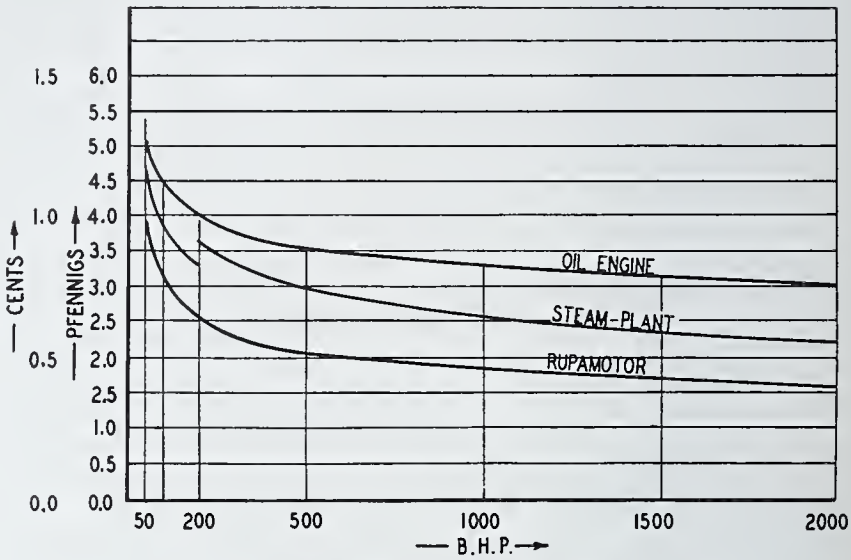
gine has been only 65 per cent due to the compressors being larger than that of a Diesel engine of equal power, which was a safety measure on the first new Rupamotor, and because the pistons are not yet worn in. This engine has shown no accumulation of slack, ash, or gum deposits on the walls. Each of the three coal dust feeding valves has two conveyor screws. Their horizontal driving worm gear housings are bolted to the cylinder head and remain in alinement after removable coupling parts and the inlet injectors are removed.

The next Rupamotor, a two-cylinder, 100 h.p. engine, is shown in Figure 16. This engine has recently been started up at the Kosmos

Works. The driving gear box of the screw conveyors on this engine remains fastened to the inlet injectors and is directly connected to a $\frac{1}{3}$ h.p. motor. The vertical coal dust supply valves, on the 150 h.p. as well as on the 100 h.p. engine, are controlled, as to amount and duration of lift, by a governor acting upon a common, horizontal rack which adjusts rotatable nuts on these valve stems. This design has worked out very satisfactorily.

Coming designs will doubtless bring further improvements and simplifications. A large sphere of action is being opened, which will offer well paying employment to thousands of industrious men and will give to the industry power which is cheap and quickly available. Countries rich in coal will be less dependent on the supply of expensive fuel oil from foreign countries. Central power plants need no longer be built on expensive land on the banks of large rivers, where real estate is high, and will not require the use of great steam turbines in order to obtain highest economy. For Rupamotors of large capacity do not surpass those of smaller capacity in fuel economy and will use only one-tenth to one-twentieth of the water used for steam plants. Since the Rupamotor is ready for service at a moment's notice without heat supply from the outside, and, therefore, avoids the time loss of one or two hours for firing up a boiler, it will soon be chosen as the peak load unit in central power plants, particularly, because the engine can be run on fuel oil just as well as on coal and is. therefore, just as reliable in regard to service as a Diesel engine. Furthermore, since many central power plants already have a pulverized coal plant, no additional equipment for the pulverization is required. The Rupamotor, even the first one of its kind, the 80 h.p. engine, produces the kilowatt hour on about 11,500 B.t.u., whereas the central power plants require at present in general about 23,800 to 17,000 B.t.u. in heat of coal. Even under the most favorable conditions and only in a few cases with very high pressure and superheat and with a plentiful supply of cold water the best figure obtained is 13,000 B.t.u. per brake horsepower one hour. Since, on the other hand, good Diesel engines of 150 h.p. use only 6400 B.t.u. per horsepower hour, we are justified to assume that on future Rupamotors the coal consumption will also be reduced to this figure. In this connection it should be remembered that the present-day methods for washing the coal, such as air separation, and screen separation of the coarser, harder, and high mineral particles, etc., are only the beginning in the art of ash separation from coal. The

many investigations now on foot all over the world on methods for removing the mineral substances from the coal will greatly benefit the Rupamotor. Furthermore, the older problems in the application of the Diesel engine, which have been postponed or abandoned on account of the high cost of fuel oil, such as for instance, the internal combustion engine locomotive, will again find larger interest. According to available reports, the firing of boilers with pulverized coal in the marine line has been a success and this success will prepare the way for the introduction of the Rupamotor for ship propul-



TOTAL COST FOR 1 B.H.P. HOUR, INCLUDING DEPRECIATION, LUBRICATION, WAGES, AND FUEL.

FIG. 17

sion. The clean exhaust gases of the Rupamotor with nothing but dry ash content contain less odor than those of the oil engine and are, by the use of simple filters, less offensive in street traffic than the present automobile gases. The Kosmos Company entertains no doubt but that the Rupamotor will be used for automobiles and, first of all, on trucks.

An estimate of the operating costs (based on conditions in Germany) of a Diesel engine, steam engine, and Rupamotor for units from 50 to 2,000 h.p. on as nearly equal basis as possible are shown in Figure 17. The diagram demonstrates the advantages of the Rupamotor, in particular, in units above 300 h.p. Allowing for a

liberal rate of interest, this engine shows a considerable reduction in the total operating costs in comparison with Diesel engines and steam plants.

The gas engine made its entrance into the world around 1867 at the World's Fair in Paris. Thirty years later, in 1897, Dr. Diesel taught us to generate power economically from liquid fuel. After another thirty years, the Rupamotor engine shows how to use solid fuels in a water-cooled engine cylinder.

During the past 25 to 30 years, the internal combustion engine as well as the before-that-time hardly known steam turbine have experienced sales running into millions of horsepower. The development of the power generating machine has demonstrated that progress always depended on reduction in the cost of power. Therefore, it is justified to anticipate that the Rupamotor can look forward to a similar development because it produces power more cheaply than any other heat engine known today.

THE POWDERED COAL LOCOMOTIVES OF THE ALLGEMEINE ELEKTRICITAETS GESELLSCHAFT

By Baurat Walter Kleinow

Hennigsdorf, Berlin

Read by Dr. Lionel Fleischmann of the A. E. G., Berlin

When my company asked me, who knows nothing of steam locomotives, to read the paper of Mr. Kleinow, who does not speak English, it seemed to me a new example of the old picture of the blind and the lame. I at once wrote Dr. Baker of my predicament which in his answer he very kindly overlooked treating me absolutely on a par with you gentlemen who have devoted a life-time to the study of heat. A personal interview did not alter this situation and when telling my troubles to Professor Trinks he in essence said, "Well if you don't know anything of lignite you at least know something of the lingo." This also was true only to a very limited extent for when I read the paper of Mr. Kleinow I saw with terror that I even did not know the meaning of a good many German terms. But then again came true the old saying of the silver lining to every cloud. I discovered the existence of a book called *Cyclopedia of Locomotives* edited by the Association of Master Mechanics and I really think the American engineering fraternity must be congratulated for the existence of this book which in its line is certainly a classic. I have in this paper used as far as possible the terms which I found there. I have not converted the figures given in metric system into English measures as, being a member of the International Electrotechnical Committee, I am pledged to uphold the metric system. However, for the convenience of those accustomed to work with these I am giving a few figures of conversion:

1 inch equals 25.4 mm.
1 mile equals 1.609 km.
1 m.^{2} equals 10.764 sq. in.
1 m.^{3} equals 35.31 cu. in.
1 kgm. equals 2.2 lbs.
1 kgm. cal. equals 3.968 B.t.u.
5°C. equals 9°F.
1 kgm. cal./m.^{3} equals 0.1125 B.t.u.

I must further add that I have in some places changed the wording of Mr. Kleinow's paper, for he has written it for publication in print which, in some instances, makes a reading accompanied by a display of slides difficult. I have left out the tabulation of the tests but I shall be very glad to show them to anybody desiring to see them. Perhaps a further explanation should be given why an electrical firm like the A.E.G. has developed a pulverized fuel locomotive. From 1901 on, my company has worked on the problem of the electrification of railroads, I being responsible for the electrical design. We anticipated a rapid development in this field and built a huge shop for the construction of electric locomotives. When electrification did not march as rapidly as anticipated, the A.E.G. took up the building of steam locomotives. In the meantime, the use of pulverized fuel in central stations became general and the question was raised whether economy of railway operation did lie in the conversion of heat into electric energy demanding a complete change in traction material, or in using low-grade fuel in the old locomotives which at comparatively small expense could be converted into pulverized fuel locomotives, so the A.E.G. is now trying both methods in competition thereby insuring a fair trial. And now I shall for some time forego my personality and act as Mr. Kleinow's loud speaker.

1. The locomotive boiler which is used throughout the world in hundreds of thousands and which practically monopolizes the field is built on the lines first proposed by Stephenson. In principle it consists of a firebox and adjoining cylindrical shell boiler containing firetubes—and when superheated steam is used in addition thereto there are flues with superheater pipes. When using pulverized fuel only the firebox can be considered the main combustion space. Calculating the volume of the firebox and comparing it with the caloric value of the fuel it will be found that this space must deliver hourly from 1,200,000 to 2,500,000 Kcal. in order to obtain an evaporation comparable to that of grate fired locomotives using good coal. The rate of heating liberation is thus several times greater than in stationary boilers fed with pulverized fuel. It must furthermore be remembered that the firebox with its watercooled copper or iron walls absorbs a large quantity of heat through radiation which is then transferred to the boiler water. This heat is absorbed from the fire during the combustion process. If a part of the firebox were lined with fire brick this would not only decrease the combustion

space but it would also render the most valuable part of the heating surface ineffective. Combustion must be completed before the flame can reach the tube sheet and the smoke and gases must have cooled down so that cinders floating in the hot gases are solidified when reaching the tube sheet. Otherwise they would with time clog the flues thereby reducing the draft and finally stopping it altogether. From the amount of the gases at high rate of evaporation the time of combustion figures out to be 0.2 second, about one-tenth to one-fifteenth of the value found with stationary powdered coal equipment.

The A.E.G. locomotive works began studying the question of applying pulverized fuel for locomotives in 1924. For this the normal freight locomotive for slight grades of the German State Railways was selected (Fig. 1) which is widely used in Germany.

2. The locomotive boiler used was set up in a shed over a pit without alteration in its construction. The coal dust was brought to the operating bunker from a storage bunker placed above a weighing bunker; from the operating bunker it was carried to the firebox by the usual method with electrical apparatus.

With this equipment numerous experiments were carried out from 1924 to 1926. From these experiments a method of firing finally developed which met the requirements to such an extent that it was felt permissible to try its use in a locomotive.

The A.E.G. method of coal dust firing for locomotives thus developed has the following characteristics.

The coal dust air mixture which is formed in two distributors contains only a part of the air required for combustion as primary air. The remainder, the secondary air, is drawn in automatically as in every ordinary steam locomotive, by exhaust pipe action. The proportion of primary air is governed by the fuel and the demands on the boiler.

By the use of secondary air, which is drawn in automatically and without expense by the exhaust, the amount of air, which must be supplied to the nozzles by a blower, is lessened. It is possible to get along with a relatively small blower. This is important, since the steam for driving the blower is lost from the locomotive itself. The entrance of the secondary air at the front sheet of the firebox below the fire baffle and its passage below the baffle cools the latter and contributes to its preservation.

The mixture of fuel and air is driven into nozzles, two in number,

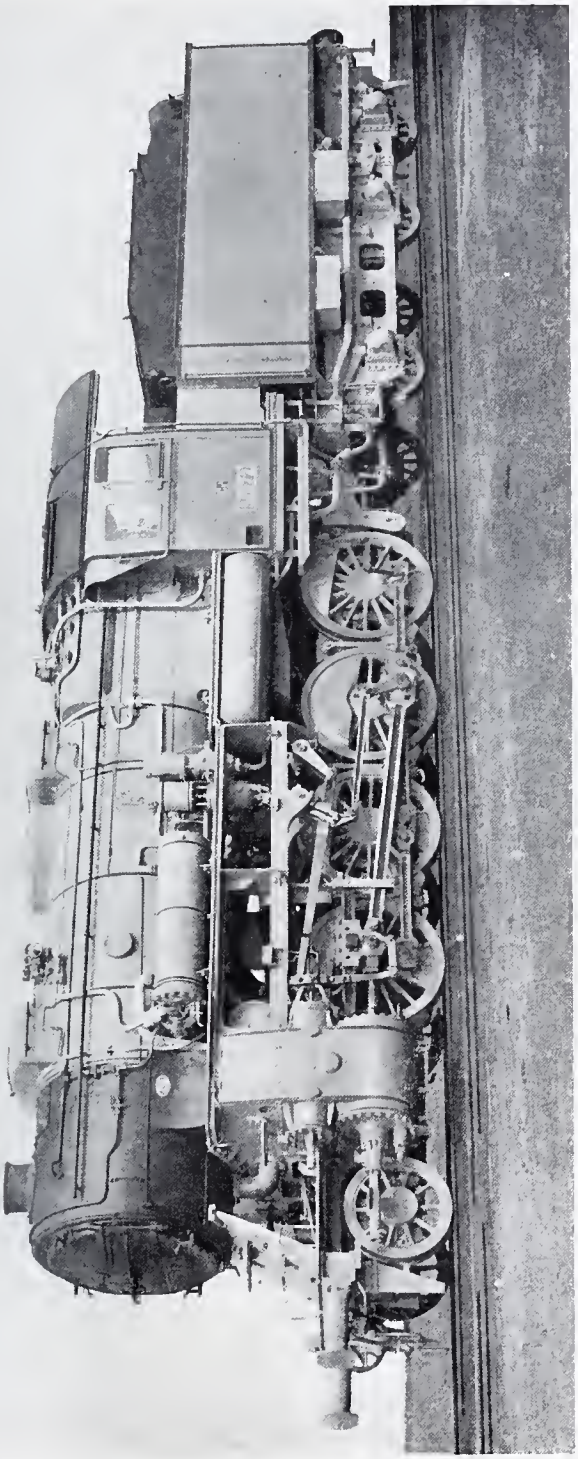


Fig. 1. 1 D Two Cylinder—Superheated Steam—Freight Locomotive Type G S^2

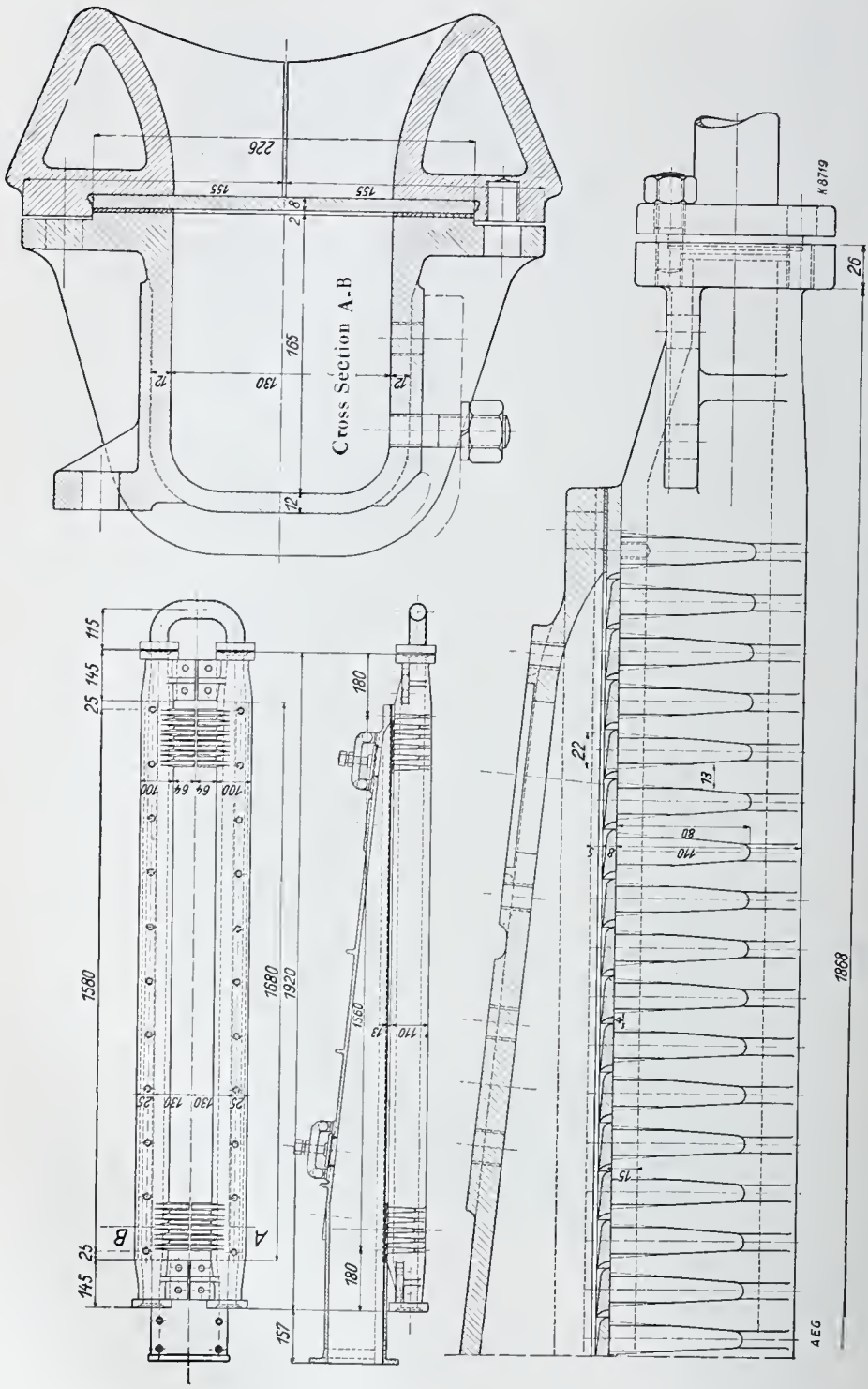


FIG. 2. SLIT NOZZLES WITH COOLING BODIES

placed opposite each other and lying below the firebox. In the nozzles the stream of coal dust and air is broken up into a great number of narrow stream bands. These are then turned 90° and meet under violent whirling motion in the center of the fire chamber. The nozzles are cooled by water jackets and the nozzle openings are protected from backfiring in the case of light load and correspondingly low air velocity.

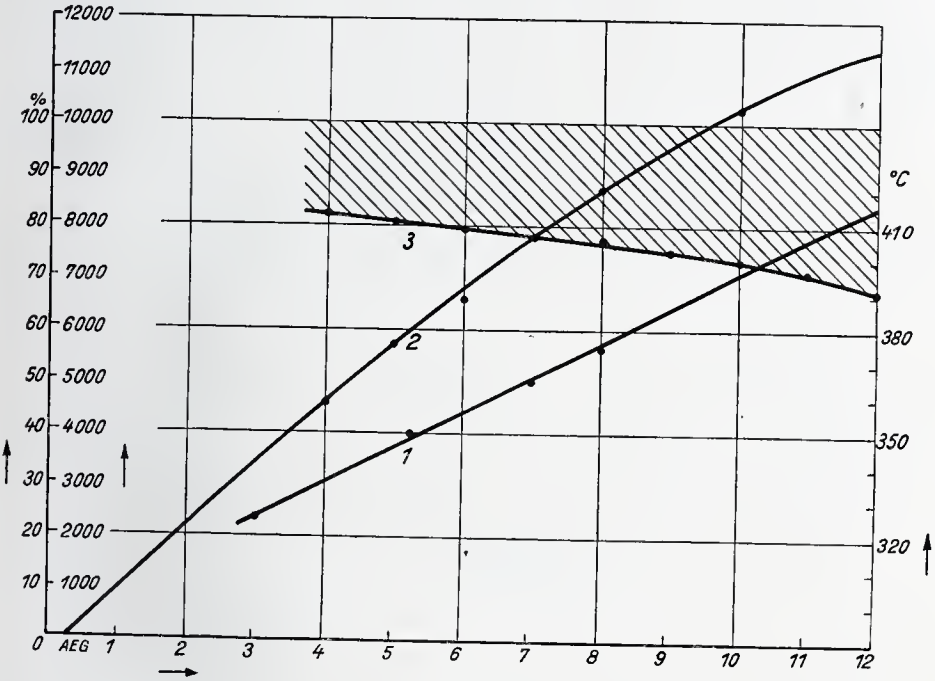


FIG. 3. HOURLY PRODUCTION OF STEAM, SUPERHEATED STEAM TEMPERATURE AND BOILER EFFICIENCY OF THE A.E.G. COAL DUST EXPERIMENTAL BOILER AS A FUNCTION OF HEAT IN THE COAL FIRED

The reason for so finely subdividing the dust air mixture into a large number of single streams (in this case 100) is to shorten the time of combustion. By placing two nozzles opposite each other the formation of a blow torch flame is avoided and at the same time a zone is situated midway between the two nozzles in which all the particles of coal dust are completely burned. Placing the two nozzles opposite one another entails a further important advantage. In the case of a light load in the boiler, one nozzle must be completely shut off. In order to avoid the formation of a blowtorch flame in this case there is run through one nozzle a mixture of coal dust and air

and through the other pure air. Experiments have shown that even in this case perfect combustion is obtained.

The rising coal dust flames meet below the fire brick arch the strongly heated secondary air.

Figure 2 shows the nozzle used. Every nozzle consists of the nozzle tube open at one side and with a cross section tapering toward the end; it further consists of the guide blades closing the open side of the nozzle tube. These break up the coal dust air mixture into narrow streams and divert them. The nozzle further possesses a water jacket placed in front of the guide blades.

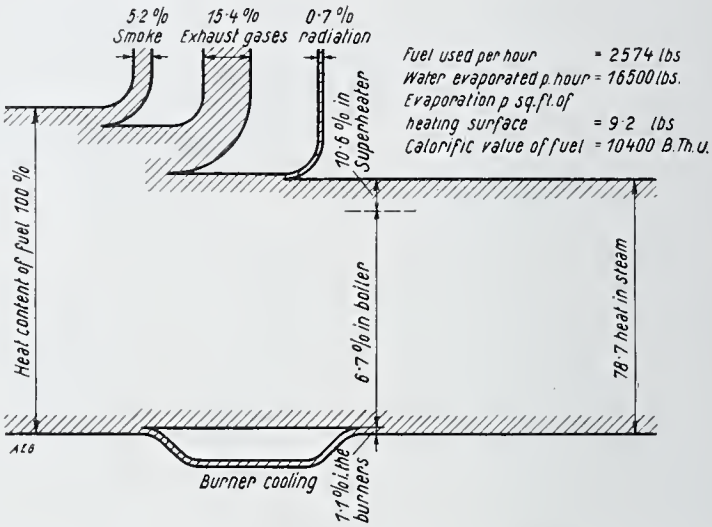


FIG. 4. COURSE OF THE HEAT CURRENT IN THE COAL DUST LOCOMOTIVE BOILER

3. *Experiments with a Stationary Locomotive Boiler with A.E.G. Coal Dust Firing.* An analysis of the coal dust ready for burning showed the following contents:

	per cent
Water	8
Ash	9
Volatile constituents	50

The lower heating value was determined at 5,720 Kcal.: 79 per cent passed through a normal sieve of 4,900 meshes per square centimeter. The fuel can be designated as especially suitable for coal dust firing.

The results of these tests can be seen from Figure 3, which shows the hourly production of steam, the temperature of the superheated steam and the boiler efficiency in relation to the heat expenditure

in the coal used. The boiler efficiency drops from 81 per cent at 30 kgm./m.^{2} to 67.5 per cent at 70 kgm./m.^{2} evaporation. By boiler efficiency is meant the relation of the total heat taken from the boiler in the form of steam to the heat of combustion of the burned coal. The steam consumed is, therefore, in the case in question not only the superheated steam for the operation of the locomotive but also the wet steam for operation of the heater feed pump and the condensed wet steam for the operation of the preheater. The temperature behind the preheater is regarded as the initial temperature of the feed water. The heating of the feed water by the nozzle cooling is credited to the locomotive boiler. The method of figuring boiler efficiency can be seen from Figure 4 which shows the flow of the heat current in the boiler.

From the tests it was perfectly evident that evaporation of 70 kgm./m.^{2} was possible with lignite even in continuous operation for hours without deposits of slag on the frontsheet causing an interruption of operation.

The deposit of slag on the frontsheet is greatly dependent on the kind of coal and on the melting point of the slag. For every kind of coal a limit can be set up to which firing in continuous operation is still possible. If the demand is increased beyond this limit nest formation on the frontsheet ensues, forcing an interruption of operation unless it is possible to remove the first deposit at once by means of a scraping device or a sand blast.

4. *Development of the A.E.G. Coal Dust Locomotive.* The favorable results of the experiments caused the German State Railway Company to give the A.E.G. the contract for the building of two steam freight locomotives with coal dust firing. This has been followed recently by an order for four more. No changes in the old tested boiler and in the tender frame were to be made. The locomotives were delivered early in 1928.

The service weight of the locomotive increased from 83.4 tons to 85.8 tons i.e., 2.4 tons. The tender holds 19 cubic meters of water and 12 cubic meters of coal dust. Its weight empty has increased from 21.0 to 25.8 tons, i.e., 4.8 tons, so that the total increase in weight of the coal dust fired locomotive over the grate fired amounts to 7.2 tons or 7 per cent of the empty weight.

On account of the limited dimensions of height and width the bunker had to be made in long extended form. In the first G 8^2 locomotive a circular cylindric form was adopted. The inner

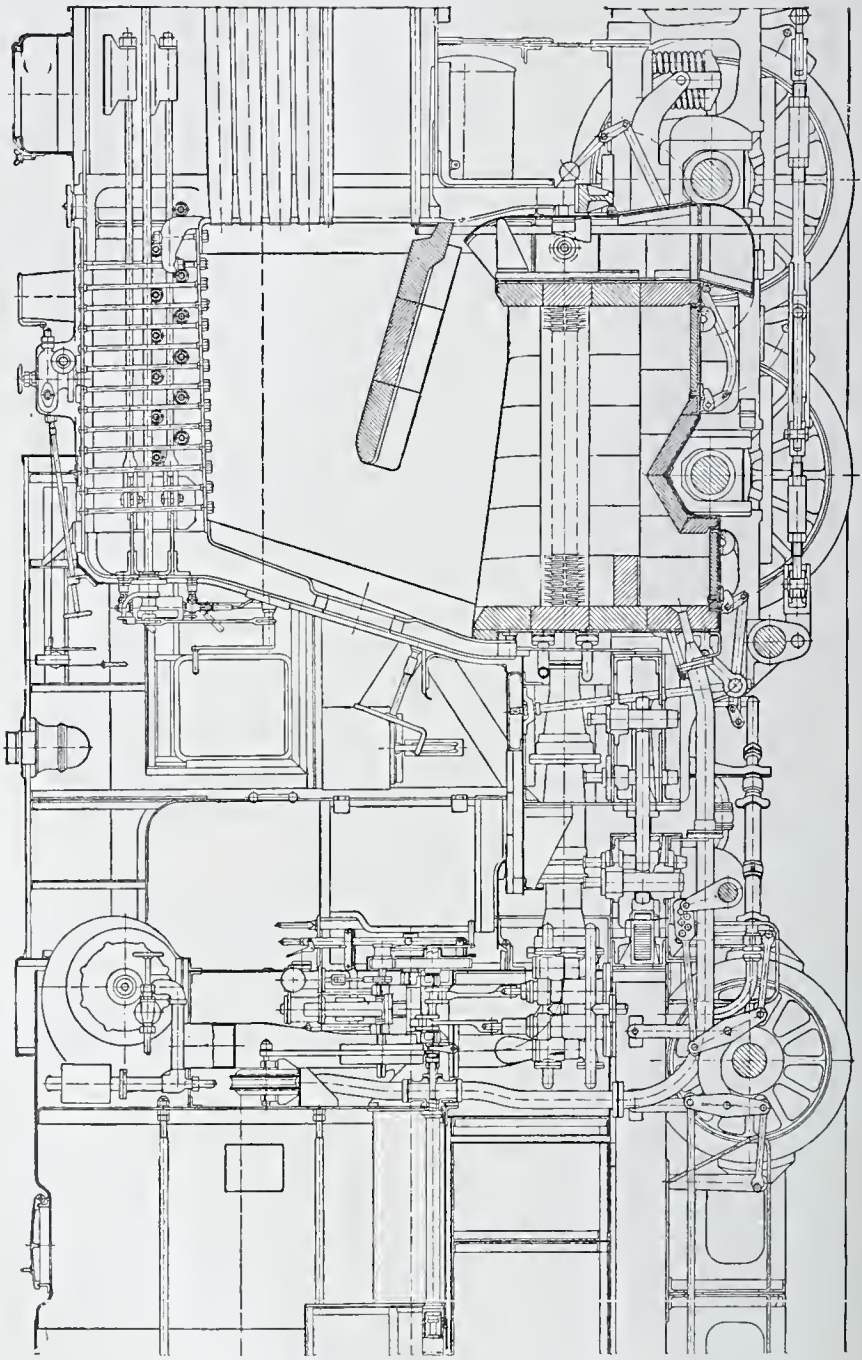


FIG. 5. LONGITUDINAL SECTION AND PLAN OF THE COAL DUST LOCOMOTIVE

diameter of the boiler is something over 2 meters, its length 4 meters. In this bunker both of the coal dust feedscrews for the nozzles were placed. They are dimensioned for conveying a total maximum of 2,100 kgm./h. At peak load they are driven at 140 r.p.m. The feedscrews are single thread and 3.5 meters long. The amount of coal dust is governed by regulating the speed of the feedscrews.

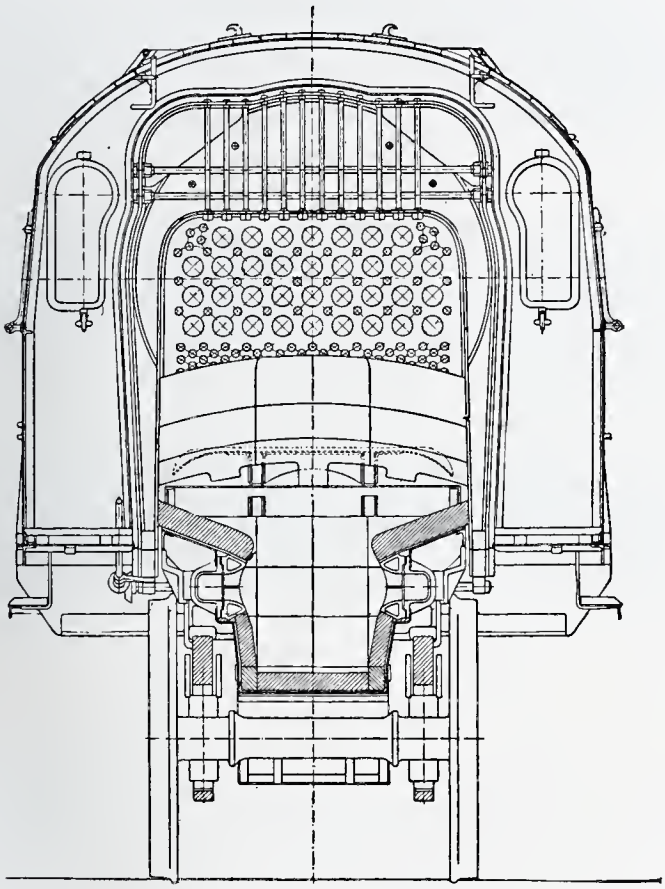


FIG. 6. CROSS-SECTION OF THE COAL DUST LOCOMOTIVE

For producing the carrying or primary air there is a blower capable of blowing in 40 per cent of the total air needed for combustion even with the highest amount of fuel, 2,100 kgm./h. Assuming the machine runs with 25 per cent excess of air this amount of air amounts to 17,500 m.^{3}/h., the primary air is therefore, about 7,000 m.^{3}/h.

In the experimental locomotive the blower is driven by a simple steam turbine. The amount of air is controlled by changing the number of revolutions of the blower and this by throttling the steam

at the turbine valve. The highest steam consumption in delivering 7,000 m.^{3}/h. against 158 mm. water pressure amounts to about 196 kgm./h.

A small steam engine with a double acting cylinder of open construction serves for operating the feedscrew. Its speed can be regulated between 130 and 400 r.p.m. At 3 atm. gauge pressure at the slide valve it drives both main feedscrews and gives at 150 r.p.m. about 0.6 hp., at 350 r.p.m. about 1.5 hp. The steam consumption varies from 30 to 50 kgm./h. The whole arrangement of the first A.E.G. coal dust locomotive can be seen from Figures 5 and 6. Here we should also mention the dampers for the secondary air, one for forward movement and one for backward movement.

We have not yet spoken of the small auxiliary burner at the back wall of the ash box. It serves as a pilot burner when the locomotive is standing still or drifting. We have already said that about 2,100 kgm. of lignite dust as a maximum is conveyed by both feedscrews when the steam engine is revolving at top speed. At 130 r.p.m. the amount conveyed amounts to 900 kgm. per hour and if only one screw is operated, 450 kgm. per hour; but for drifting this is still too much. Therefore, a small auxiliary burner and a small auxiliary feedscrew are provided. This conveys 30 to 75 kgm. per hour of dust and is just sufficient to cover the loss by radiation from the boiler and to deliver steam for the air compressor. The auxiliary feedscrew is situated in the center of the front part of the bunker. It is operated by the engine by means of an intermediate shaft.

In order to permit shutdown of the turbine blower and to save its steam consumption when the locomotive is standing, a special small blower is provided for the auxiliary burner, which is driven from the flywheel of the engine through a friction wheel. It is attached to the front wall of the coal dust bunker. The steam engine stands in the center and drives by means of a belt over an intermediate pulley two gears placed on the shafts of the main feedscrew which can be connected with them by friction couplings. The intermediate shaft serves to drive the auxiliary feedscrew and the cooling water pump for the main nozzles. The steam engine is started with a crank.

The turbine blower is set high. It carries the primary air through a hose tube to the two distributors.

The mixture of coal dust and air for the main nozzles is carried through 2 pipes 160 mm. in diameter to the locomotive.

A few words should be said about the nozzle cooling. This cooling which is effected by pumping the boiler feed water through the nozzle by means of a feedwater pump driven by the steam engine. The operation by the steam engine makes it certain that the cooling

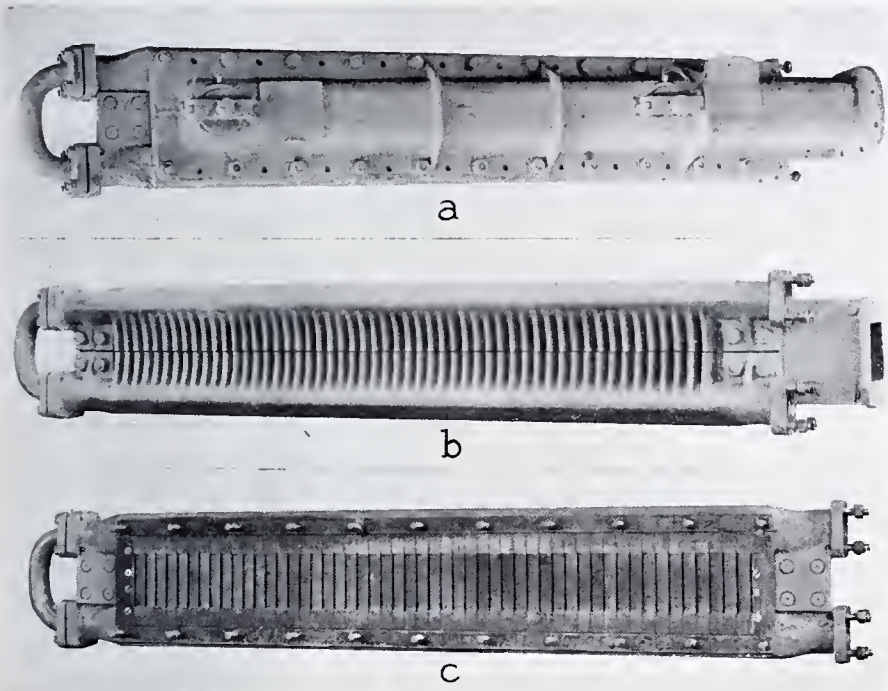


FIG. 7. VIEW OF THE NOZZLE

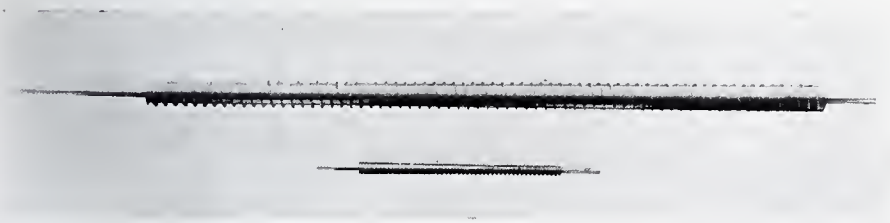


FIG. 8. VIEW OF A MAIN AND AN AUXILIARY WORM

system operates whenever there is a flame. The pump is set so deep that the water flows to it without suction head.

Since the pump delivers only about 40 per cent of the feed water as cooling water, it comes about that whenever a feed pump works, not only this cooling water but also fresh water is drawn in. There-

fore, all water heated in the nozzle reaches the boiler. Only in the rare case when the firing system works without being fed does the cooling water flow back into the tender.

A nozzle is shown in Figure 7a; the complete nozzle seen from the outside in Figure 7b, after the removal of the air chamber. Figure 7c shows the nozzle seen from the side towards the fire. Figure 8 shows on the same scale, side by side, a main and an auxiliary feed-screw.

5. By the courtesy of the railway officials of the district of Berlin opportunity was given the A.E.G. to test the locomotive thoroughly in actual service before delivery.

In the continuous tests, the tested locomotive was tried out for several hours under constant speed, constant steam pressure, constant water head in the boiler, and constant indicated horsepower. For this purpose the experimental locomotive was loaded not with a train but with a locomotive working as a brake and with a test car in between. In this kind of a locomotive the valve gear is set for motion in the opposite direction to travel, so that the steam engine acts as a compressor.

Before starting the trip from the roundhouse the freshly coaled tender was weighed on a very accurate Schenk scale. Before weighing all water was let out of the tender so as to prevent any mistake in measuring the water. The main coupling between locomotive and tender was removed, so that reactions of the locomotive on the tender were prevented. The locomotive was then hauled to the starting point of the experimental run by the brake locomotive. During this time only the heat loss of the boiler had to be covered by coal dust firing. For this the auxiliary burner was used, the consumption of which for each operating hour is sufficiently accurately known. During the whole experimental period the revolutions of the main feed screw were counted. After returning to the roundhouse the empty tender is again weighed without water. The difference between the two weighings showed the consumption of coal dust. From this was deducted the consumption of the auxiliary burner according to the number of hours of its operation, further the consumption of the feedscrews for heating and steam generation according to number of revolutions. In this way exceptionally accurate values were obtained. Since all tests were extended to at least 129 minutes and the maximum to 247 minutes with perfectly constant working conditions the values obtained by the test department of Grunewald must be recognized as notably accurate.

Arranging the eleven tests according to fuel heat given hourly to the boiler we find that this increased from 1.41 million Kcal. to 10.8 million Kcal. per hour. The heating value of the coal hovered around 5,300 Kcal., the water content was about 12 per cent, the ash content 9 per cent, the deposit through a normal sieve of 4,900 meshes to the cm.^{2} varied between 76.3 and 89.1 per cent. The heating surface load was increased from 11.2 kgm./m.^{2} per hour to 63.3 kgm./m.^{2} per hour.

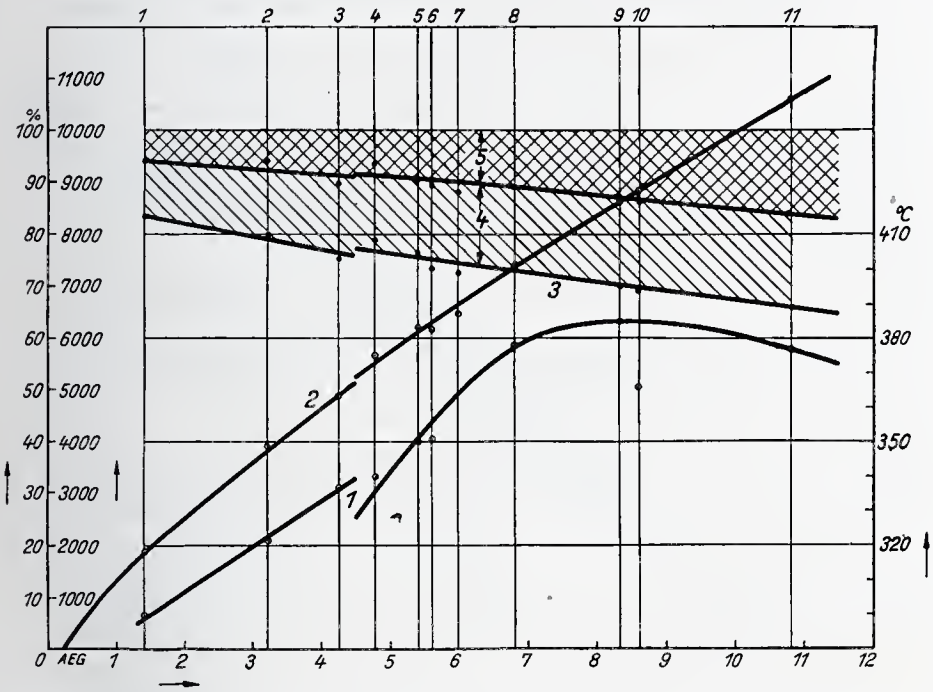


FIG. 9. HOURLY PRODUCTION OF STEAM, SUPERHEATED STEAM TEMPERATURE AND BOILER EFFICIENCY AS A FUNCTION OF HEAT IN THE COAL FIRED

The boiler efficiency is determined according to the diagram, Figure 6 showing the flow of heat. It contains therefore the heat given up to the cooling water as useful heat.

In the calculation of the heat used up in steam it was assumed that 7 per cent of the total steam was used as low pressure steam by the auxiliary machines and 4.5 per cent for the preheater feed pump and air pump, 2.5 per cent for the feedscrew device and the turbine blower.

The admission was increased from 19 to 40 per cent. With the exception of experiments 1 to 3 in which only one main feedscrew was

in operation, two worms were always used at full speed. The slide valve pressure amounted to 13.5 atm. gauge pressure. The indicated horsepower was calculated from the indicator cards, the drawbar pull was determined in the test car and corrected for the grade.

The indicated horsepower was increased from 77 hp. running light to 1,425 hp., the draw bar performance from 0 running light to 1,364 hp. The turbine blower and the coal dust feedscrews would have sufficed for an output of 1,400 hp. at the drawbar.

The most important results are given in the form of curves.

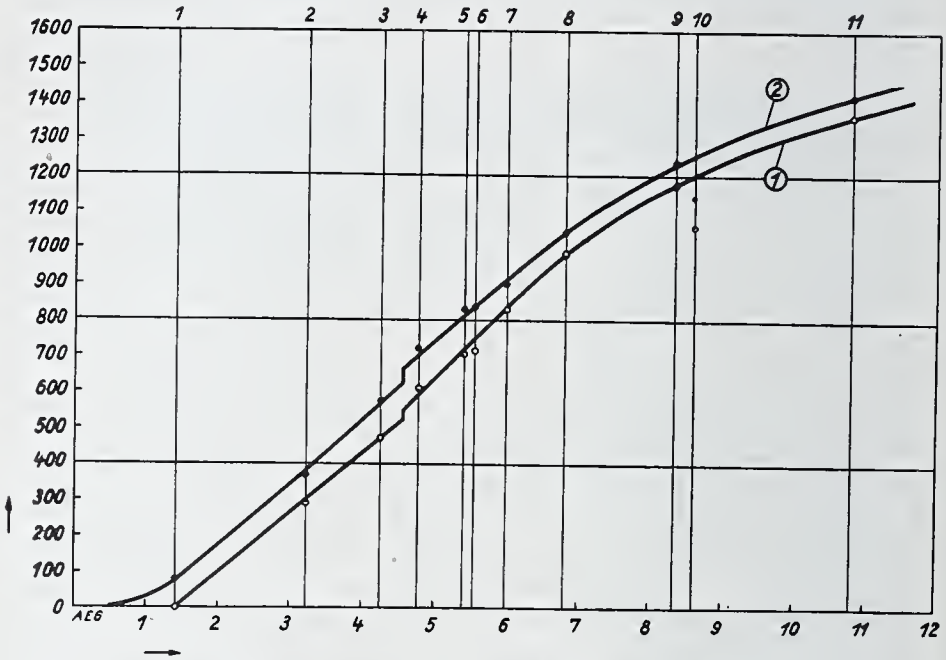


FIG. 10. INDICATED EFFICIENCY AND DRAWBAR EFFICIENCY AS A FUNCTION OF HEAT IN THE COAL FIRED

Figure 9 shows the hourly production of steam in relation to the heat produced by the coal, the superheated steam temperature and the boiler efficiency. The various tests arrange themselves with but little scattering into a natural order.

Figure 10 shows the indicated horsepower and the drawbar horsepower on the level, in relation to the heat produced by the coal. The difference between the two curves is the power used for the propulsion of the locomotive proper and for auxiliary apparatus.

Figure 11 shows the consumption of steam in relation to drawbar output as well as the steam consumption for each drawbar-horse-

power hour. It is seen that the most favorable steam consumption of 7.3 kgm. lies at 1,150 hp.$_e$h.

Figure 12 is still more important, showing the heat expenditure in relation to the drawbar performance. Here the best value lies at only 1,000 hp.$_e$, which is to be explained from the fact that with more admission and output the steam is highly superheated and passes through the exhaust causing a new source of loss.

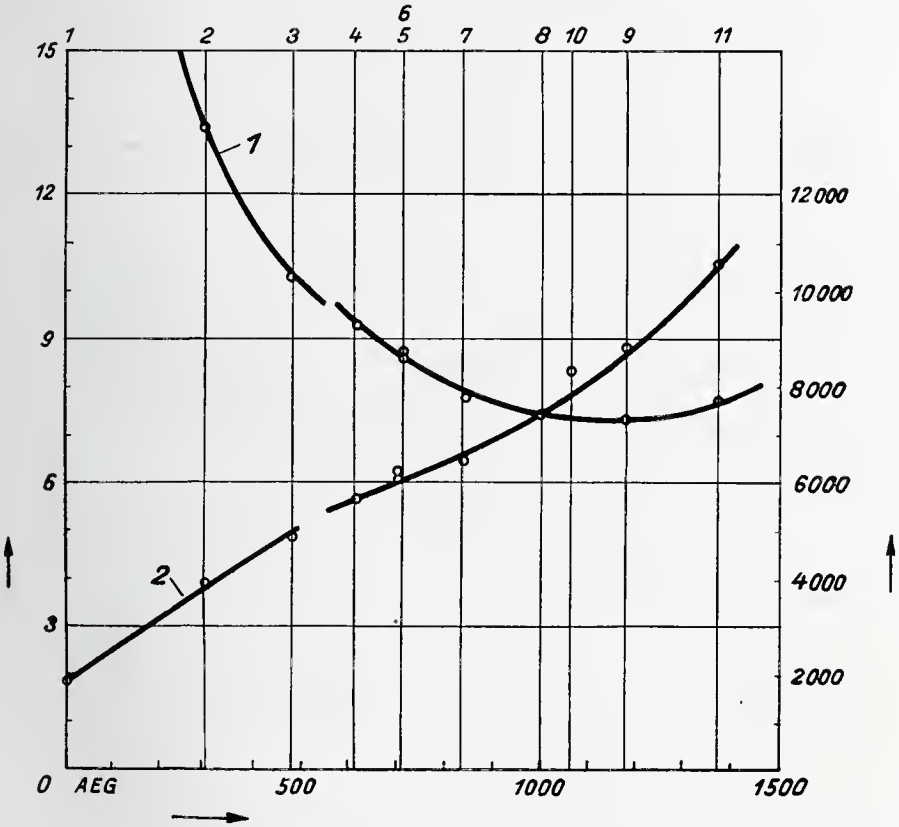


FIG. 11. VARIATION OF STEAM CONSUMPTION OF STEAM BOILER DRAWBAR HORSEPOWER

The best result is 6,850 kgm. cal. per hp.$_e$ hr. drawbar output.

Figure 13 shows steam consumption in relation to the indicated horsepower. The most favorable steam consumption is very nearly 7 kgm. at 1,100 hp.$_i$, the most favorable heat expenditure 6,450 Kcal. at 950 hp.$_i$ as taken from Figure 14.

The maximum heat supplied to the locomotive boiler during 150 min. (= $2\frac{1}{2}$) hours amounted to 10.8 million Kcal./h. The volume of the firebox from the center of the nozzle upwards, i.e., the volume of

the combustion chamber, is 4.14 m.^{3} The firebox chamber is therefore heated with 2.61 million Kcal./m.^{3}h. Since in this test 16 − 1 (loss by radiation) per cent = 15 per cent remained unconsumed, therefore actually 2.21 million Kcal./m.^{3}h. were developed in the firebox. The time of combustion is calculated at 0.16 second by assuming a mean temperature of 1,200° in the firebox.

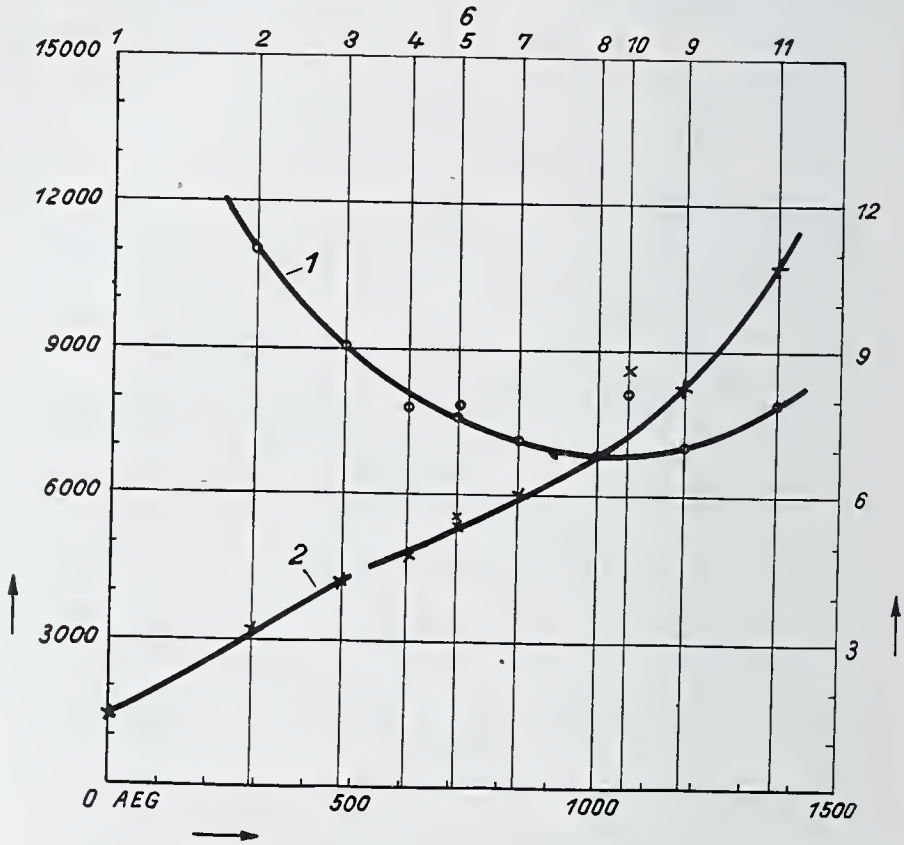


FIG. 12. HEAT CONSUMPTION AS FUNCTION OF DRAWBAR HORSEPOWER

In all tests the frontsheet remained practically free from slag deposits. A bad effect on the suction action causing an increase of the vacuum in the smoke chamber could not be observed.

Apart from the continuous tests with constant indicated horsepower five actual runs were made by the test department of Grunewald. Trains of 734 to 1,189 tons weight were run over the 78 Km. stretch. The drawbar performance with reference to the grade and time under steam varied between 371 and 532 hp. The elevation of the

test course can be seen in Figure 15. Between Brück and block 53 a difference in level of 116 m. must be overcome. The longest and steepest grade was 8.35 per cent. The locomotive is here strained to the limit of its boiler and adhesion. The heat consumption for each gross-ton-kilometer (the locomotive weight with 2/3 supplies was set at 128 tons) varied between 98 and 124, between 109 and 140

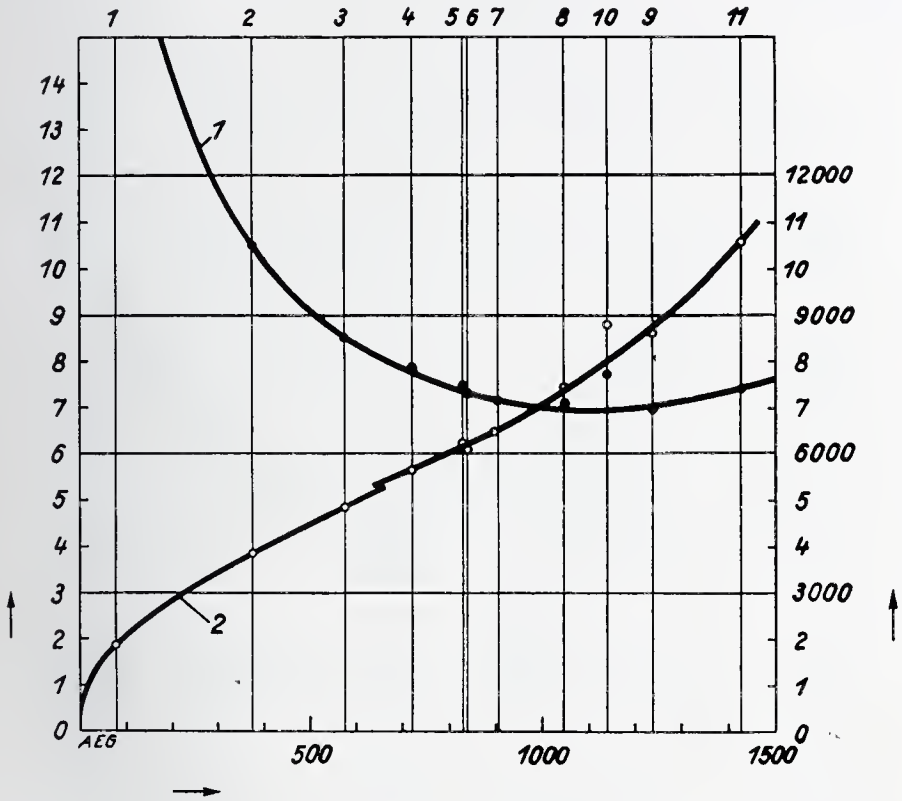


FIG. 13. STEAM CONSUMPTION AS FUNCTION OF INDICATED HORSEPOWER

Kcal. for each net ton kilometer. The G 8^2 coal dust locomotive must therefore be characterized as a very economical machine.

It is also a matter of interest to know how steam consumption and heat production of the coal dust locomotive compare with the usual locomotive with grate firing. The most recent and very extensive publication of the German State Railway on this subject is the treatise of Professor Nordmann, member of the State Railway Engineering Office, "New Theoretical and Economic Results of Tests with Steam Locomotives" in Annalen of July 1, 1927. In this treatise

there are two diagrams which show the relation of heat produced by the coal to the performance and to the indicated horsepower for a large number of locomotives. The first mentioned of these illustrations is reprinted here as Figure 16.

The G 8^2 locomotive is designed for 12 to 14 atm. boiler pressure, likewise the G 8^3 which has the same boiler as G 8^2 but has 3 steam cylinders.

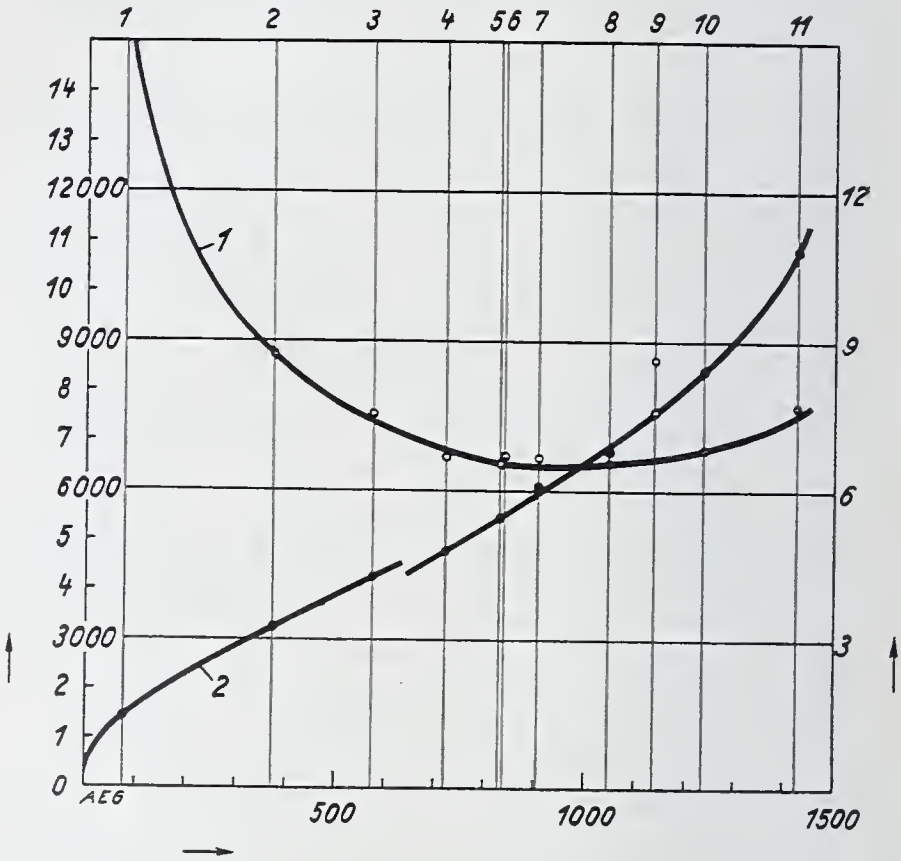


FIG. 14. HEAT CONSUMPTION AS FUNCTION OF INDICATED HORSEPOWER

The G 12 is a 1 E superheated steam freight locomotive with 3 cylinders and a boiler of 195 m.^{2} total fire-exposed steam heating surface.

The K locomotive is the former Würtemberg 1 F superheated steam four cylinder-compound-freight locomotive with 232 m.^{2} heating surface.

The Gt 2 X 4/4 is the former Bavarian D + D superheated steam

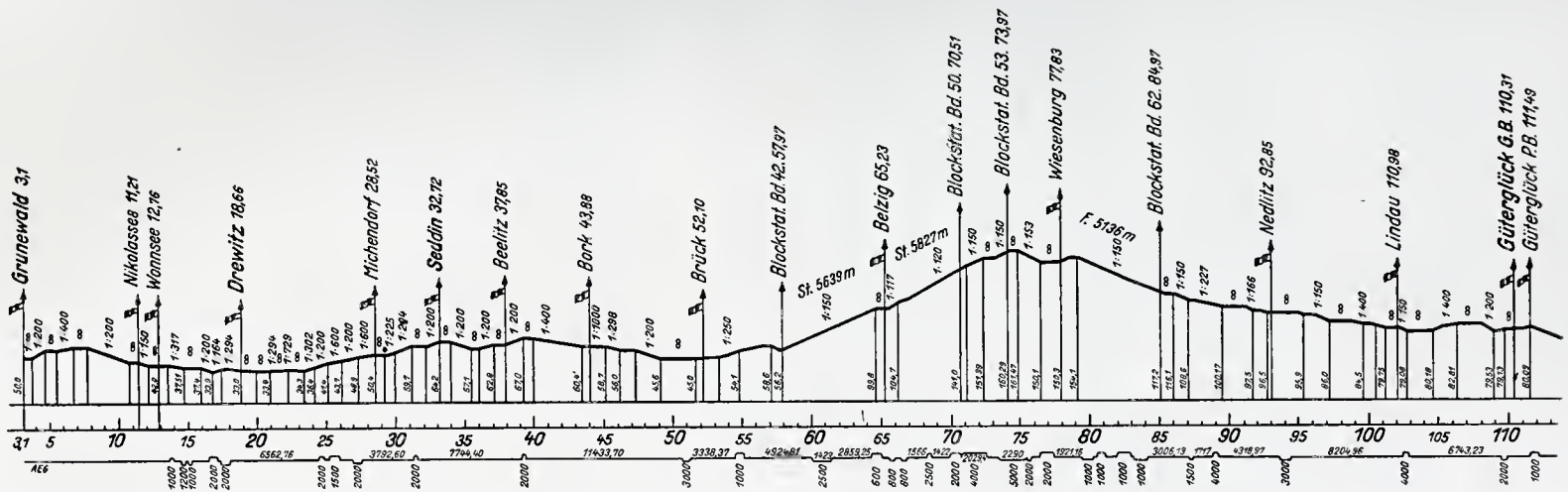


FIG. 15. LEVELS OF THE EXPERIMENTAL TRACK OF THE GRUNEWALD-SEDDIN GUTERGLUCK LINE

four cylinder-compound-tender locomotive with 231 m.² heating surface.

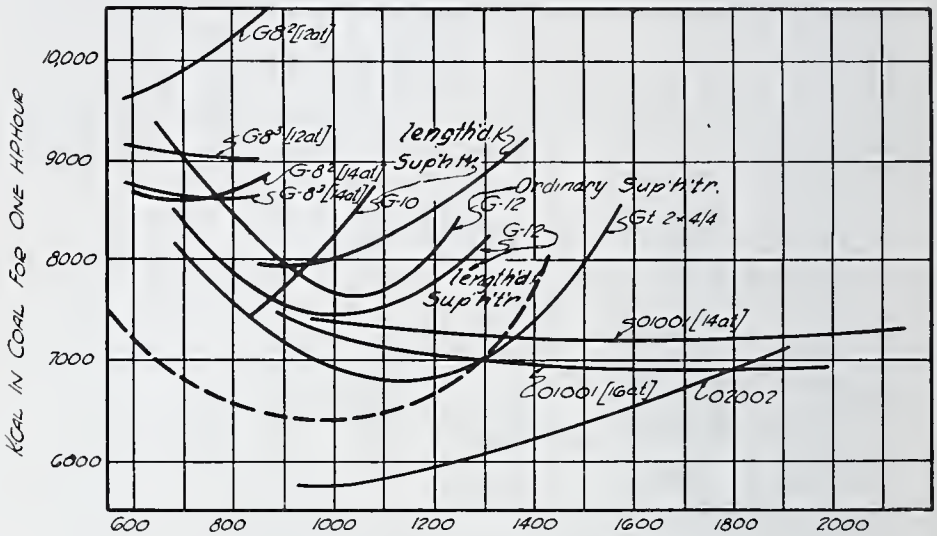


FIG. 16. RELATION OF HEAT IN COAL FIND TO THE BRAKE HORSEPOWER FOR A NUMBER OF VARIOUS LOCOMOTIVES OF THE STATE RAILWAYS

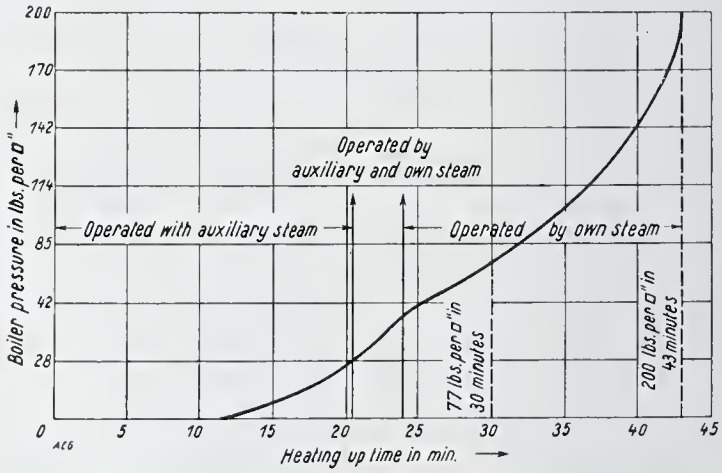


FIG. 17. INCREASE IN PRESSURE DURING FIRING OF THE BOILER OF THE A.E.G. COAL DUST LOCOMOTIVES

The locomotives 01001 and 02002 are the new unit-express-locomotives of the German State Railway with two cylinder-twin, or four cylinder compound-arrangement with a boiler of 238 m.² heating surface.

The lines for heat production of the G 8^2 coal dust locomotive are put into the diagrams shaded. It is seen that the coal dust locomotive in its field up to 1,200 $hp._e$ surpasses the other freight locomotives as regards heat production for $hp._e h.$ and $hp._i h.$

The impression which the coal dust locomotive made on those participating in the tests is described in an address by Professor Nordmann, "Coal Dust Firing in Locomotives" ("Braunkohle," 1928, vol. 29). The pertinent passage is here quoted literally:

"The most impressive observation of all the participants in the test runs was doubtless this, that it was possible in a simple and very rapid manner to accommodate the rapidity of combustion to the locomotive output which often varied with the grade. At a signal from the engineer that a lighter or heavier firing of the boiler was necessary it was possible for the fireman within a very short time to change the revolution of the feedscrew and consequently the coal dust feed by a proper adjustment of the engine regulator. Also the correlated regulation of the primary air, which because of its somewhat lesser importance as compared with the secondary air was not handled with the same care, was easily possible.

"The second striking point is the great reduction in labor for the fireman resulting from the fact that he does not have to shovel coal as in an ordinary locomotive but has simply to regulate the combustion process."

Maintenance work on the firebrick of the firebox or the brick arch was not necessary during the three months of continual tests in Grunewald. Also in other ways the coal dust locomotive showed itself to be a perfectly reliable machine.

Due to the good results of the tests, the two G 8^2 coal dust locomotives of the A. E. G. were adopted by the German State Railway. They are in regular freight service in the district of Halle (Saale).

6. *Method of Operation. a. Firing.* For firing the cold boiler auxiliary steam of 5 to 6 gauge pressure atm. is used. This must be furnished by another locomotive or a stationary plant. It is introduced through the steam line.

The steam is necessary:

For operating the exhaust nozzle.
For operating the steam engine.
For operating the turbine blower.

After the steam engine has been started so as to operate the nozzle cooling system a piece of waste soaked in oil is put in the ash pan and

lighted. Next the auxiliary burner is started. As soon as a bright flame appears the turbine blower is started and one main feedscrew is also started. The quantity of fuel blown in depends on the suction of the exhaust nozzle which must be able to carry off the gases produced. In twelve minutes the boiler pressure begins to rise, in twenty-four minutes the auxiliary steam can be cut off. All auxiliary devices can now be fed from their own boiler pressure. In thirty minutes the boiler pressure reaches 5.5 atm.; with which it is possible to move out of the round house. In ten minutes more the boiler pressure is 10 atm. gauge pressure; in three minutes more, i.e., after a total time of forty-three minutes, the full boiler pressure of 14 atm. is reached. Figure 17 shows the pressure rise during the firing of the coal dust locomotive in relation to time.

If the time of departure has not arrived, the large feed screw and the turbine blower are shut down. The engine runs with the small auxiliary feedscrew and the auxiliary blower. The main blower is not needed.

b. Operation. Just before departure the turbine blower and then one or both of the main feedscrews, as the case may require, are started. The quantity of coal is determined by the speed of the steam engine and is read from a tachometer. The quantity of air is given by the steam pressure. The fireman has a table showing proper values for each kind of coal.

Except under heaviest loads the smoke gases leaving the smoke stack must be clear; no unburned ash must be present. The amount of coal to be burned is determined as in grate firing, in general by the strength of the draft through the exhaust nozzle, for more heating gases must not be produced than are carried out by the exhaust to the smoke stack. Otherwise excess pressure results in the firebox and as a result sparks and smoke appear at the fire door. Nevertheless in coal dust firing we are much more independent of locomotive load than in grate firing. It is easily possible therefore to accumulate steam when approaching a grade.

Under lighter load one feedscrew is cut off. Through one nozzle a coal dust air mixture is introduced and through the other pure air. In this case the fire burns just as well as when both nozzles are feeding coal dust.

The regulation of the firing is much more simple than might at first be expected. Generally the fireman sets the firing for the mean load. If he thinks it important to maintain uniformly the maximum steam

pressure he regulates by means of the feed pump at the expense of the heat of the boiler. Only in the case of rather large deviations from the normal water head does he regulate the firing.

c. Shutting Down. If no more steam is needed the firing is entirely stopped. In doing this the ash pan dampers must always be closed so that no cold air passes through the boiler. The fire brick holds the heat for about ten or fifteen minutes, sufficiently to enable renewed ignition. For longer pauses the auxiliary burner is set in operation.

7. *Advantages of Coal Dust Locomotive Firing and Principles for its Economic Valuation. a. Low Purchase Price of Fuel.* As a fuel for high boiler efficiencies such as are customary in Germany only high grade lump hard coal with low ash content can be used. Coal dust firing makes it possible to use fire coal and waste which can be had at a lower price because they are hard to sell. This condition will not change essentially even with a high consumption of fine coal, because the easier sale of fine coal offers opportunity to the coal mines to achieve a reduction in the cost of operation by changing to machine working which entails an increase in fine coal waste.

Coal dust firing also makes it possible to fire with coals richer in ash which would result in frequent interruptions of operation with grate firing due to formation of slag. But with coal rich in ash the boiler efficiency cannot be raised as high as with those poor in ash.

The possibility of firing with peat and lignite is especially valuable. These in a raw state cannot be used for the locomotive grate and even when refined in the form of brown coal briquettes they are still poorly suited. In dust firing, however, the lignite, because of its high content of volatile constituents, is an especially valuable fuel.

b. Independence of Coal Quality. The great independence of coal quality makes it possible to burn at any place the coal which is most easily available and thus in some cases to save very considerable freight charges. This is especially the case in localities where there are lignite or peat deposits and which are far removed from regular coal fields.

Furthermore there is always the possibility of changing the kind of coal and of taking the fullest advantage of the existing market conditions.

c. Good Fuel Utilization. Coal dust locomotives require a lower expenditure of heat for indicated and actual horsepower hour than do grate fired locomotives. The saving is due to the higher boiler efficiency and the greater superheating of the steam.

d. Possibility of High Loading and Long Duration of Load. The tests already made have shown that without change in locomotive boilers built for grate firing higher output together with longer duration can be attained from the boiler fired with coal dust than from the grate fired boiler.

e. Short Time Required for Firing. Because of the short time required for firing it is possible to keep fewer locomotives under steam than was formerly necessary. Thus unnecessary losses by radiation are prevented. These savings become more important the longer and more frequent are the pauses in operation.

f. Rapid Adaptation to the Demands of Operation. The very easy regulation of firing according to the steam requirement does away with all the difficulties of grate firing. Blowing off of the safety valve under heavy fire due to a sudden stop before a signal or at delayed starting is avoided, as well as slagging the fire during times of long pause. When it is possible to proceed, the full boiler pressure can again be reached in a few seconds. When, at the end of a grade which must be made with high boiler pressure, no steam is needed, the firing can be stopped at once. On the other hand full use can be made at any time of the boiler reserve in order to avoid heavy strains on the boiler which are accompanied by poorer efficiency; for at the end of the grade it is possible to restore normal water head and steam pressure in a short time.

g. Avoidance of Flying Sparks. There is but little smoke and no sparks at all. Thus damages for fires caused by flying sparks along the right of way are avoided.

h. Relief for the Fireman. The heavy physical work of the fireman ceases with the coal dust locomotive just as it does with automatic stoker firing and to an even higher degree. The fireman perfectly fresh physically can give his whole attention to the most economical use of fuel and can actually help the engineer in watching the track and the signals. Since the fire door does not need to be opened the blinding of the engine crew at night is avoided.

In the selection of firemen it is no longer necessary to place such great emphasis on physical strength as in the case of grate firing.

PULVERIZED FUEL AND ITS VARIOUS FIELDS OF APPLICATION

By Dr. George E. K. Blythe

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Read by Thomas G. Estep, Jr., Associate Professor of Mechanical Engineering, Carnegie Institute of Technology

In the combustion of pulverized fuel four stages occur, namely, (1) heating and drying the fuel, (2) gasification of the volatile matter and coking the carbon, (3) combustion of gases, and (4) combustion of the coke particles. In practice, these phases overlap to some extent.

The most rapid ignition and combustion possible is desired to obtain the highest furnace temperatures, and thus the highest efficiency. The small pulverized coal particle entering the furnace is first of all heated up by stages. Any moisture in the coal must be vaporized. The drying process is endothermic; that is, the furnace walls surrounding the flame must furnish this heat to raise the temperature of the incoming particles and to start distillation, which is the next stage. While some of the radiant heat is furnished by the surrounding walls, the greater part comes from the flames of burning coal and gases.

This reverberatory action of the flame is highly important, particularly with low volatile coals. The distillation change starts at about 400°F., and gases and volatile vapors are given off, forming smoke until combustion starts. The distillation process is also endothermic, unless the oxygen content of the coal is high. The entering coal particle, being a black body, readily absorbs radiant heat, and increases in temperature.

The primary air which accompanies the coal is a poor absorber of radiant heat, and may have increased in temperature only slightly, when the gases begin to distil. In fact, the air is heated largely by convection from the coal particles suspended in it, and which are absorbing radiant heat. The smoky gases from the coal contain carbon particles which continue to absorb radiant heat, thus increasing their temperature. Finally, the air-gas mixture reaches ignition temperature, and combustion of the gases commences.

The burning of the volatile matter produces water vapor and

carbon dioxide, both of which will absorb and also give out a considerable amount of radiant energy. It has long been known that the radiation emitted in furnace gases is chiefly due to carbon dioxide and water vapor. The amounts of radiation from each gas are found by examination of their spectra, to be in three bands of wave lengths. It is possible to determine the intensity of radiation in each wave length for a given temperature of the gas and integrate these over the width of the band, thus determining the gross emission from the gas. This emission is found to be a percentage by volume content of the gas, thickness of the gas volume and its temperature. The combustion of the volatile matter be considered a step by step process where the hydrogen first unites with oxygen, freeing the carbon in an atomized state, but highly heated by the burning hydrogen. Undoubtedly, a certain amount of heat, resulting from the combustion of the hydrogen, is absorbed and dissipated as radiant heat by the free carbon particles, which are nearly pure black bodies, and which give luminosity to the flame. Experiments have shown that luminous flames with incandescent particles of carbon floating in them radiate more heat than non-luminous flames.

More radiant heat is emitted and may be absorbed from the flames of a pulverized coal furnace than from those of a stoker furnace, due to this large volume of flame of greater luminosity. Much of the secondary combustion in the flame with stokers is due to the carbon monoxide, which burns with a non-luminous flame, and hence, has less radiating power. The rapidity with which the free carbon particles in the pulverized-coal furnace combine with oxygen depends very largely on the speed of mixing with heated air. This is true of the coke which now forms the remainder of the original coal particle. The speed of combustion of this coke and the consequent length of flame travel are dependent upon rapid mixing.

Unless the products of combustion of the volatile gases are swept away from the coke, it remains surrounded by inert gases. Oxygen cannot reach the particle until this gas envelope is removed further along the flame travel. The coke takes an interval of time to burn, and fresh supplies of oxygen must reach the coke throughout the whole combustion period. The extent of mixing necessary can be appreciated from the fact that the particle of coke must come into contact with many thousand times its own volume of air under furnace conditions in order to burn completely.

Violent mixing is, therefore, an essential of rapid combustion and

short flames. Turbulence of the mixture has been found desirable for rapid ignition in solid-injection oil engines, and turbulence in the furnace is also an essential factor in the burning of pulverized coal.

The application of pulverized fuel to various forms of metallurgical heating has been the means of greatly increasing the efficiency of working.

Coal fired furnaces have been ignored until recently as being unworthy of consideration where efficient plant is required, the majority of steelworks' managers looking upon furnaces of this type as a cheap makeshift only. This state of affairs results from the popularity in the British steel works of raw producer gas for furnace heating. This is consequent upon the fact that there has always been a plentiful supply of producer gas, wherever steel melting furnaces are found and its marked success in the case of melting furnaces has induced engineers to give special attention to adapting it to metallurgical furnaces in preference to considering the more difficult problem of improving the coal fired furnaces.

Working results covering a period of many months are now available, fully confirming the great economies which pulverized coal has brought about in the firing of annealing furnaces, tunnel and batch, heavy and light forge furnaces, puddling, malleable-iron melting, copper refining and nickel reverberatory furnaces.

The highest attainable temperature for heating is obtained with pulverized coal because of the small amount of excess air required. Large amounts of excess air would greatly reduce the attainable temperature, and as the transmission of heat from the hot gases to the mass to be heated is the more rapid as the temperature gradient becomes more pronounced, it is fairly obvious that the higher the temperature in the combustion chamber the higher the efficiency of working; the small amount of excess air present reduces the loss of metal due to scaling. The heat produced in pulverized-coal-fired furnaces soaks through the metal more uniformly than in furnaces fired by hand, gas, or oil. Consequently, heated billets, ingots, plates, etc., can be worked for a much longer period without having to be reheated.

In regard to the actual fuel economy affected by the use of pulverized fuel, the following recent figures are illuminating: In a furnace running on tin slag, a charge requiring ten hours to work on hand firing involved the consumption of $37\frac{1}{2}$ cwt. of coal. The introduction of pulverized fuel enabled the same furnace, working on a charge of

the same weight and operating under identical conditions, to complete the charge in seven hours with a coal consumption of only 11½ cwt. The time saved thus amounted to more than one working day per week, while the fuel economy was some two-thirds of the former coal bill.

Two further instances may be given. A non-ferrous reverberatory furnace having a throughput capacity of 9 tons of metal 24 hours, consumed, under the original hand firing conditions 4 tons of coal. When the Buell burner with necessary pulverizing equipment was installed, it was found that no less than 16 tons of metal could be dealt with in the same period, while the coal consumption was only 3 tons. Finally, a furnace in use by the United Water Softeners Ltd., for the manufacture of their well known specialty "aboromite" which requires to be most carefully preserved from the slightest contamination with dust, and was, therefore, gas fired, has been changed over to pulverized coal firing utilizing the Buell burner and associated equipment. Not only has the dust question been solved to the entire satisfaction of the Company, but the very substantial saving of £600 per annum has been effected on the Company's fuel bill.

TURBULENCE AND WATER COOLED WALLS IN PULVERIZED COAL FIRED FURNACES

Time after time it has been stated that pulverized coal burns like gas or oil. Nothing could be further from the truth than statements of this nature. As a matter of fact, in the powdered form a solid non-volatile fuel is the most unfavorable condition for rapid combustion. In the case of gas, the higher the velocity of a gas jet, the greater will be the speed of combustion provided, of course, sufficient time is given for diffusion. The speed of combustion of the gas jet would be dependent upon the degree of induction entrainment and turbulence, but the same is not true in the same measure for pulverized coal. The length of time required for combustion remains approximately the same regardless of the velocity of injection—so unlike the combustion of gas. Further, it does not matter how finely pulverized the coal particles may be, it remains essentially a solid, and the conditions necessary for combustion of solid carbon still apply to the "fixed carbon" consitutent, which will comprise anything from 50 to 93 per cent of the total combustible, and that although the rapidity of combination of carbon with oxygen increases

with rise of temperature, the principal limiting factor is the rate at which oxygen can be brought into contact with the carbon and this depends on the thickness of the film of carbon-dioxide and nitrogen formed on the surface of the carbon. The thickness of this film is inversely proportional to the relative velocity of the gases and solid. It, therefore, follows that the rate of combustion of the carbon is directly proportional to the rate at which air is supplied. In the case of oil, the particles are first broken up as small as possible by the atomizing agents, and then vaporized by heat, after which the conditions are similar to those for burning gas, though less favorable for complete combustion since decomposition of the oil liberates particles of carbon and if these strike cold surfaces before being completely burnt they will form deposit of soot.

PULVERIZED FUEL EQUIPMENT

A typical installation for burning pulverized fuel includes arrangements for (1) conveying (in some cases), preliminary crushing, (2) drying, (3), pulverizing, (4) transporting the coal to the furnaces, and (5) feeding to the burners, together with the necessary equipment for the supply of air for combustion.

The systems in use divide themselves into two distinct classes. The unit system and storage system. The chief characteristics of the unit system is of course the absence of any storage of pulverized fuel, the raw coal being fed to the pulverizer, and from the pulverizer direct to the burners. In many types of unit pulverizers preliminary drying is not considered necessary because the moisture content in the coal is driven off during its stay in the pulverizer by means of preheated air. The absence of any reserve supply of fuel is considered to be a disadvantage in many applications, for the reason that should the pulverizer break down or become inoperative from any cause, the plant would necessarily have to be shut down.

Ball and ring roller type pulverizers are now so constructed as to enable them to function on the unit principle without any greater liability to interruption of service than any other mechanical firing devices.

DRYERS

The necessity for drying the coal before pulverizing has been often called into question, particularly by operators whose coal supply is normally of low moisture content. The facts are inescapable, how-

ever, that drying the coal considerably increases the capacity and reduces the power consumption of the pulverizers, and makes its handling after pulverizing a positive instead of a doubtful operation. Damp pulverized material is one of the most refractory substances to handle, hanging up and blocking operations at every point possible, and its transportation is unreliable and a continuous annoyance. When dried, the fuel mixes and burns more readily in the furnace, and, as the moisture must be removed either before or after entering the furnace, the effect on fuel economy is almost negligible.

The presence of moisture in coal, like ash, must be regarded as a dead loss. Generally speaking, moisture reduces the available boiler efficiency more than an equivalent amount of well-burnt ash, and is, therefore, an expensive diluent which should be avoided as much as possible.

FIG. 1. ARRANGEMENTS OF AN INDIRECT FIRED TYPE ROTARY DRYER

Two types of dryers are available—the rotary, which has been standard for many years, and the vertical stationary type, of comparatively recent development. The former consists of a rotating shell, slightly inclined, and ribbed internally, through which the material passes by gravity in conjunction with the rotation of the dryer. The hot gases usually pass around the outside of the shell before entering and flowing through it, and are in direct contact with the material, which is picked up by ribs and dropped across the path of the grass. This is known as the indirect-fired type of rotary dryer (Fig. 1).

The vertical dryer is a sectional box through which, in the usual arrangement, the coal flows by gravity on its way from the storage bin to the pulverizer. Hot gases, under fan pressure or suction, pass through the interstices in the body of the material, and carry off

the moisture. These gases are preferably taken from the boiler stack, in which case the term "waste-heat dryer" is usually used. Steam-heated surfaces may also be incorporated in this dryer to assist the evaporative action of the gases. The fact that the dryer is stationary and occupies much less space than an equivalent rotary dryer, not to mention its lower cost, makes it preferable under certain conditions.

Cyclones are essential for removing the dust in the discharged gases from a rotary dryer, and are desirable with a vertical dryer, particularly when the coal contains a considerable proportion of fines. A large volume of comparatively low-temperature gases is generally desirable, and pyrometers or thermometers are used to permit proper control. In summer there may be times when the coal will be sufficiently dry before entering the dryer. In that case, the coal is passed through the dryer as usual, but the hot gases are eliminated.

Broadly speaking, dryers can be divided into four main classes:

1. Dryers designed so that the hot gases pass into the dryer and come into direct contact with the coal. This practice is not recommended owing to the loss resulting from distillation of volatile constituents.

2. Dryers designed so that the hot gases pass right through a central tube in the drier to the fan end and then return in contact with the coal.

3. Dryers arranged so that a division of the hot gases takes place, a small portion finding its way into the dryer in contact with the fuel, and the major portion heating the exterior of the dryer shell before entering the dryer.

4. Dryers designed so that the furnace gases envelope the exterior of the drier shell, none passing into the dryer until the temperature of the gases has been reduced to the safe point.

The terminal temperature of the coal as it leaves the dryer should be not more than 250°F., but latitude in this direction is governed by the nature of the coal, its ash, and its sulphur content. Apart from the attendant disadvantages in pulverizing and conveying coal containing a high percentage of moisture, a direct heat loss is occasioned, due to the fact that the vapor formed is discharged to the atmosphere in a superheated condition. Each pound of water present in the coal requires a total of approximately 1,250 B.t.u. to allow its escape with the flue gases. If, then, a coal were to contain 10

per cent of moisture, there would be a loss of approximately 125 B.t.u. per pound of coal due to the effect of moisture alone.

There exists a point beyond which drying cannot be carried out economically. The major portion of the moisture content of fuel is surface moisture, while the remainder is "inherent" or "chemically combined" moisture. The former is driven off easily, the latter with difficulty. When solid fuels are dried beyond the point at which their hygroscopic moisture is in equilibrium with the atmospheric moisture, they tend to absorb moisture if left exposed to the atmosphere. This fact may be observed particularly well in connection with lignite.

Transporting of Pulverized Coal

When the coal has been pulverized, it must be transported to the point of use. A number of methods are available, the oldest being the spiral screw conveyor, operating in dust-tight steel troughs. This type of conveyor has many defects, however, as it is hard to keep clean, is dangerous unless given proper attention, and requires considerable power, overhead runways, and often numerous motor drives, since the distance over which one flight can be operated is limited.

Another conveying system consists of a pressure-tight tank, a source of compressed air, and a pipe line leading from the bottom of the tank to the destination. In operation the tank is nearly filled with pulverized coal, and sealed, and compressed air is then admitted above the coal which forces the latter through the pipe line, discharging from the line into the furnace bins. In this sytem of coal transporting the disadvantages of the screw conveyor are eliminated, but other faults are discovered, these being that more labor is required in the operation, that the coal must be accepted and discharged in batches, and that the large volume of air required makes cyclone dust-collectors at the discharge end essential.

A third system, which is rapidly coming to the fore, consists of a pump having as an impeller a high-speed steel worm which takes the pulverized coal from a hopper and forces it into a pipe line. A small amount of compressed air is admitted into the material just beyond the discharge end of the worm, and the mixture of air and coal is forced through the pipe line to the destination. The worm is specially designed to compact the material as it approaches the discharge end of the pump, and this packing effect serves to prevent the return of

compressed air through the worm to the hopper. As a result, the pump may be operated with an open hopper as long as an adequate supply of material is received by the hopper, which makes it ideal for transporting the coal from the mill spout to the furnace bin in one operation. The whole system is enclosed, so that there is no opportunity for dusting between the time the coal enters the mill and the time when it is delivered into the bin at the furnace. The system is also used to take pulverized coal from a storage bin and distribute it to various points as required. A complete electrical signalling system is used to indicate to the operator when the bin to which he is pumping has been filled, and to permit him to operate diverting valves to change the flow to other bins which are in need of coal. The operation is usually made automatic in order to avoid any chance of overflow. This system of conveying has been used to elevate pulverized coal over a hundred feet, and to convey it distances of over a mile, the line pressure and the power required, which is comparatively low, depending upon elevation and distance. But little compressed air is required, and hence no cyclone is needed at the point of discharge from the pump line. The material as discharged is completely fluid, and levels off perfectly in the bin, retaining this condition for sometime. In addition to the advantage of dustlessness, simplicity, and adaptability, the first cost of this system is low, and likewise, the charges for labor and repairs, while repairs are easily and expeditiously made.

BUELL BURNERS

1. Of the dispersive Buell burner and the non-dispersive Buell burner, the former is the more characteristic, and is illustrated in section in Figures 2 and 3. The curved fuel-supply pipe *f* is prominent in both figures. The coal is discharged through an annular space round the internal primary-air inlet *a*, this space being greater or less according to the position of the hollow cone *b*, which forms the end of the inlet pipe. Outside the fuel inlet are two concentric casings *h* and *i*. The inner one *h* carries a pair of conical rings *c*, expanding from the direction of the jet, while the outer casing *i* terminates in a conical portion contracting against the direction of the jet. The external primary-air supply from the fan is introduced through the annular space between *h* and *i*, either from a continuous chamber *g*, or, more normally, through four pipes, connected by a common ring. The secondary air, induced by the injector action of the coal stream,

enters through louvres at *j* into the space between the inlet pipe *f* and the casing *h*. These louvres are distinguishable in Figure 2 as is also the ring for the external primary air which connects to the supply pipe from the fan. The pipe shown in the upper half supplies the internal primary air. Sometimes the external primary-air pipes function as secondary air inlets, in which case the louvres are closed.

The working of the burner will be followed from Figure 2. The internal primary-air inlet *a* is adjustable horizontally by a screw motion controlled by a hand-wheel. The hollow cone *b* is made with a solid central cone, so that the jet of air issuing from it is, like the coal stream, hollow. When the cone is in the extreme forward position *1*, the jet of coal dust has been opened out only a little way by the

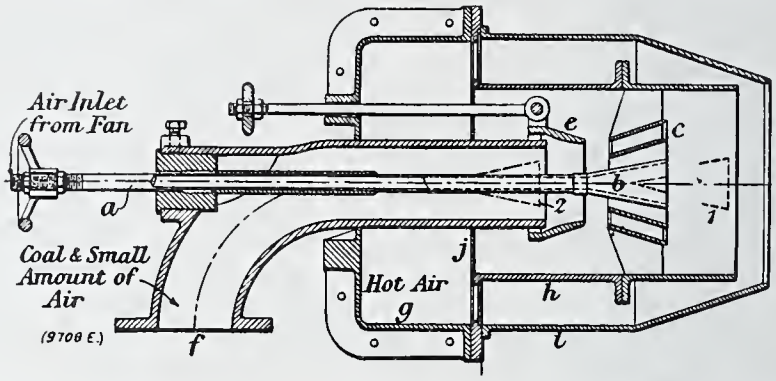

FIG. 2. DIAGRAMMATIC ARRANGEMENT OF BUELL DISPERSIVE BURNER

internal primary-air jet when it meets the converging stream of external primary air at the mouth of the casing *h*, the two streams striking one another at an acute angle. The result is a comparatively long flame carried between the two sheets of eddying air. When the cone *b* is drawn back to the extreme rearward position *2*, the coal stream is opened out immediately it leaves the inlet pipe, to such an extent that it impinges on the edge of the casing *h*, striking in its course the rings *c*, which break it up and assist in mixing it with the air. At the outer edge of the casing *h*, the coal stream, which is then spread over seven-and-a-half times its original area, meets the external primary air at a less acute angle than in the former case, and the destruction of the velocity effected by the converging currents is more marked. There is, under these conditions, a region of combustion immediately outside the mouth of the burner, where a turbulent

effect is very noticeable. The velocity of the coal and air jets being absorbed in creating this disturbance, the resultant flame is short and of a bushy character, with practically perfect combustion. The shape of the flame can, obviously, be varied between the two limits by suitably adjusting the cone between positions *1* and *2*. One important feature of the burner, which is shown in Figure 3, has not yet been alluded to. This is the conical ring *e* over the end of the coal-inlet pipe. By means of this it is possible to change the flame

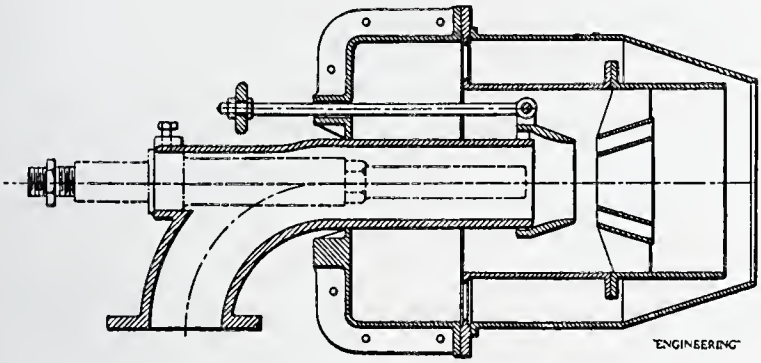

FIG. 3. DIAGRAMMATIC ARRANGEMENT OF BUELL DISPERSIVE BURNER ADAPTED FOR OIL FIRING

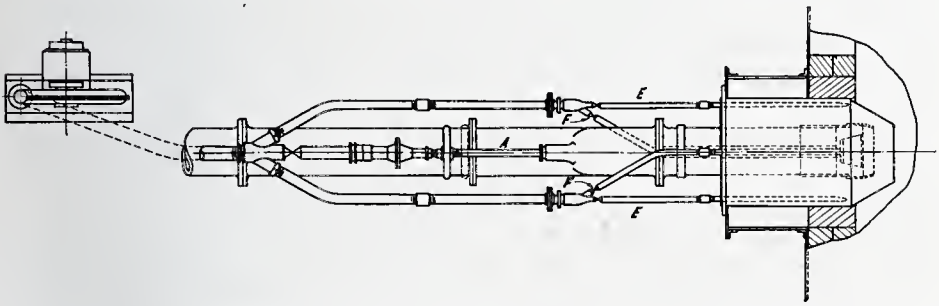

FIG. 4. ARRANGEMENT OF BUELL DISPERSIVE BURNER FOR USE WITH CEMENT KILNS, ETC.

from a strictly axial direction to one at a considerable angle to it, a feature which is very useful, in some cases, with industrial furnaces. The ring is pivoted in the middle, and can be tilted round this axis by the sliding rod shown, the fuel stream being diverted either upwards or downwards as required.

2. The non-dispersive burner Figure 4, has a long flame, suitable for such applications as cement kilns, etc. Internally, the cardinal difference between the two types is that in the non-dispersive type

the casting *h*, Figure 3, tapers inwards, and the rings *c* are omitted, while a sliding sleeve is fitted over the coal-inlet pipe, so that the position of its outlet end may be varied relatively to that of the tapered casing, and the width of the zone of junction of the secondary air with the coal supply can be controlled. Behind the end of the coal-inlet pipe, in the foreground of Figure 4, is a triple branch for air from the fan. The center pipe of this branch runs through the burner to the end of the sliding sleeve above mentioned, which is, indeed, controlled through the movement of the pipe by the hand-wheel shown. The two side pipes run into the external primary-air space, each of them dividing on the way so as to provide the four air pipes previously mentioned. Each of these pipes is fitted with a stop valve for the purpose of regulating the volume and distribution of the external primary air, which is a very important point when the calorific value of the coals used varies from time to time.

Going back only a space of a few years the largest steam boiler unit only had a steaming capacity of approximately 100,000 pounds per hour, and today no stoker-fired boiler is in operation with a rating in excess of the one mentioned. It will, therefore, be advantageous to consider the position of stoker firing in relation to pulverized fuel firing in order to decide upon what form of firing these large units and larger units of the future will be subjected to. Gross efficiencies of 87 to 89 per cent are being obtained on large boilers fired with pulverized fuel. Such efficiencies leaves very little room for improvement. These figures may be attained on short tests on stoker fired boilers, but it is fairly obvious that they will not be weekly figures all the year round. The efficiencies and flexibility obtained with pulverized fuel has started a race for supremacy between the stoker and pulverized fuel equipment designers, but boilers fired with pulverized fuel have reached such huge dimensions that it is to be wondered whether the race for supremacy between the two classes of firing can continue much longer.

The development of larger units renders every feature of design—from the point of view of stoker designers—more difficult. Expansion, air distribution and control, together with heavy loads over long periods, are among the many problems which increase with the size of the units, and at best, the breakdown hazards increase with the multiplicity of parts in the furnace.

The competition has, however, been a healthy one, and has given the stoker-designers satisfaction in the fact that they have developed

equipment in order to overcome many of the difficulties they encountered. But, unfortunately, with the present day exacting requirements with large units, in the form of higher combustion rates, higher steaming capacities, higher efficiencies and increased CO_2 percentages in the exit gases, have all tendered to inflict conditions on stokers that has resulted in excessive maintenance charges and since the tendency with pulverized fuel is to bring down initial capital costs, increased reliability and affect low maintenance charges, one can at once see that stokers for large boiler units are placed at a disadvantage, whereas in the case of pulverized fuel firing, the fact of being able to burn a wide variety of low grade fuels, without having to affect the operating procedure, flexibility in following a widely fluctuating load at a high boiler efficiency, are all strong and very valuable points in favor of pulverized fuel firing for boilers of the sizes referred to.

Pulverized coal firing on a large scale in Europe has only been possible through the free use of American data and practice, and in this connection mention must be made of the installation at the Lakeside Station of the Milwaukee Electric Railway and Light Company.

This plant in the past has been the experimental station of the world, but of recent years great strides have been made in the Old World and we in Europe—look forward to the day, which we hope is not far distant, when the United States of America will look to one of our super-power stations for the latest practice.

DISCUSSION

MR. VERNON LEACH (Peabody Coal Company, Chicago, Ill.): No mention was made of the effect of sulphur on this powdered coal Diesel. I would like to have an expression on that.

PROFESSOR E. A. ALLCUT (University of Toronto, Canada): With reference to the first paper, which was read by Professor Trinks, I am sure all of us have been interested in the remarkable record of achievement in connection with this solid fuel Diesel type of engine. I do not know how fair it is to ask Professor Trinks to answer questions, in view of the absence of the author, but perhaps he may be able to give us some information on the following points.

In the first place, the coals used, I believe, were mainly lignites and some anthracites. Lignite contains a considerable amount of moisture and I should like to know how far the moisture content of the coal affects the operation of the engine. It is usual with coals having a high moisture content to partially dry them before they are put into the hopper. I should like to know whether any considerable amount of drying occurs in the coal hopper on top of the en-

gine. If so, it would be necessary to vent the hopper and in that case I should imagine there would be quite a possibility of explosions taking place on account of the possible access of air to the coal through the vent.

The second question relates to the feed worms on top of the cylinder. I am not quite clear, though perhaps it was brought out in the paper, how the feed-works operate when the load is suddenly taken off the engine. Suppose the engine is reduced to half load, what happens to the feed of the coal? I understand that there is a certain amount of aeration before the coal goes to the worms in order to make the coal flow more freely. In that case, if there be no by-pass to the coal at the end, and the feed worms are designed to deliver the maximum quantity of coal, what happens when they start delivering half that quantity? The full quantity of coal is at one end and considerably less is going out at the other. In that case, the coal must pack, unless there is some overflow provided for the excess fuel to escape.

The third question is about the character of the coal used. No mention was made, I believe, of the question of caking coals. Is it possible to use caking coals in this particular type of engine?

The next question relates to some discrepancies that I noticed, or thought I noticed, with respect to some of the claims made for the engine. From the figures given, it is obvious that the heat consumption of the engine is something like 20 per cent more than that of the Diesel engine. Assuming there is no change in the proportion of the total heat given to the cooling water, and there is more heat required to produce a brake horsepower hour, it seems obvious that the remainder of the heat must go into the exhaust. It is claimed that there is neither deposit of solid matter inside the cylinder nor smoke in the exhaust gas. Another claim made later on in connection with its use in industries, is that the gases were less noxious than those issuing from the gasoline; therefore, presumably, there is no carbon monoxide in the exhaust gases. If allthese claims are true, I should like to know where the extra heat goes to.

It was in my mind before Professor Trinks mentioned it, to say something about the question of ash, because I know that in the early pulverized coal engines ash caused a considerable amount of trouble. It is claimed that this engine has solved that difficulty, but in this I should like to take issue with him. It should be realized that ash is going into this cylinder all the time, and it is probable that a steady supply of this kind will cause considerable trouble.

EDWARD RAHM, JR. (Kennedy-Van Saun Manufacturing and Engineering Corporation, New York, N. Y.): Dr. Pawlikowski does not mention the degree of fineness of pulverization of the coal fed to his engine, nor do the curves shown indicate any grinding costs deducted when comparing his engine with steam or oil engines. If the degree of fineness of pulverization is too great, the law of diminishing returns would come into operation and the engine would prove impractical commercially, although a success from a mechanical standpoint. I would also like to know something of the performance with bituminous coal in this country. It seems to me that the brown coal of Germany which is extremely friable, would have better economic results on this engine than the American coals.

MR. HENRY P. REID (Universal Portland Cement Company, Chicago, Ill.): One of the gentlemen spoke of the fineness. As I remember it the paper stated the fineness must be the same as in boiler furnace practice. That varies so, it doesn't give us much information. Therefore I would like to have a little more detail on it.

As to the fineness of ash, I cannot yet see with the average fineness, or with the fineness of probably everything through a 200-mesh sieve, which mesh has become more or less a standard measure of fineness, that it would result in ash particles small enough to get no abrasion on the cylinder walls or none of those particles between the piston ring of the wall.

Then as to the moisture. My question is the opposite of the one previously asked. Instead of how much moisture must be taken out of the coal, I should like to ask whether or not in working with this engine it has been found necessary to have moisture present in the coal in order to insure a rapid combustion, the moisture being used as a catalyzer for the reaction. It is impossible to get a rapid combustion with dry carbon or dry hydrogen.

How about the proportion of the air and coal in the compressed air injection jet to give the proper relation of combustion air to coal at all times and maintain a high thermo efficiency? Does this setting have to be changed from time to time as different veins of coal may be used, differing in analyses, and so forth?

Lastly, I would like to ask about the coal fed into the chambers, whether or not it is by gravity only and what method is used to insure a free flow of coal when the screws are shut down, as I understood they were, after starting up one of the engines? How do they maintain a uniform flow of coal at all times, under all hopper conditions? That question I think, if it can be answered, will help a good many of us.

MR. SERGE NICHOLLS (Bureau of Mines, Pittsburgh, Pa.): I would like to ask Professor Trinks if he can give us any analysis of the exhaust gases from this engine. I believe that might clear up some of our doubt as to its action, and particularly as to whether such analysis has been carried on to find out how far coal particles of a given size may have been carried out unconsumed.

MR. F. C. GREENE (Old Ben Coal Corporation, Chicago, Ill.): I would like to ask Professor Trinks if he has heard anything of what is known as a carbon-alpha method of producing molecular carbon which is reputed to be used in these coal dust engines.

CHAIRMAN ORROK: I will now ask Professor Trinks if he can answer some of these questions, and then we will pass on to the discussion of the other two papers.

PROFESSOR TRINKS: I will answer those questions which I can answer, and then pass the rest on to Dr. Pawlikowski.

I believe I indicated in the paper what I consider the secret of Dr. Pawlikowski's success. He is, in Görlitz, located on the brown coal, on the lignite. The German brown coal is of such a nature that if you expose it to the air it becomes crumbly, it becomes powdery.

The German brown coal is very easily powdered. As soon as the moisture is taken out by exposure to dry air it becomes a powder of its own accord and the cost of pulverization is almost nothing, very much in contradistinction to our American, Pittsburgh or Illinois, bituminous coals. As a consequence all Dr. Pawlikowski had to do was to buy himself a set of sieves and sift the coal until he had a powder all of which passes through a 300-mesh sieve. That is the stuff he uses in his engine.

If he had injected the powder which we use in our boilers, some particles of which are very coarse, then it is quite evident that there would be a great deal of trouble.

As far as the feed worms are concerned, I believe it was made clear from the paper that the feed worms are not used after starting the engine—that there are simply feed pipes from the overhead hopper. Since the feed worms are not used now there can be no packing of the coal.

With regard to caking coals, I believe they were used for a short time. Dr. Pawlikowski has used everything imaginable in coal and it has worked. However, the answer to the question why the heat consumption is greater than that of the Diesel engine will have to be given by Dr. Pawlikowski himself, and I shall be only too glad to write him.

Also, with regard to analysis of exhaust gases, I think he will be very glad to furnish that.

Coming to Mr. Greene's question about the carbon pulverization method, I believe we have a paper in this conference on that method. It will be answered there.

With regard to proportion of the coal to the air with different coals, I do believe that it will call for a different adjustment every time; whenever you change the nature of the coal it will call for a different adjustment of the coal supply valve. I will ask Dr. Pawlikowski to give some details on these questions and answer them as best he can.

DR. RUDOLPH PAWLIKOWSKI (by letter, in reply to questions forwarded by Prof. Trinks): With regard to the coal which we used in the Rupa motor, I give an analysis below. The coal which we used has about 55 per cent external moisture when mined. It is dried by steam in tubes or on disks. During the drying it disintegrates into grains and powder which latter is not suitable for briquetting and is used by us in the motor. The moisture content varies between 10 and 14 per cent. The following gives the data on the coal. Specific gravity 1.43, ignition 229°C., lower calorific value 4,964 cal./kgm. The percentage of contents are: moisture 10.17, ash 8.13, carbon 55.15, hydrogen 4.57, sulphur 0.91, nitrogen 0.62, oxygen 19.91, volatile matter including water vapor 43.35.

Concerning the gravity of coal, up to the present we have not noticed any difference in using bituminous coal with more or less caking quality. When burned on the grate, caking coal obstructs the passing of combustion air and requires that the fuel bed be broken open at intervals. In contradistinction thereto, free burning coal should lie on the grate without being disturbed. Similar observations have not been made by us in the Rupa motor. We have only found the following differences in the different brands of coal. Bitumi-

nous coal from Upper Silesia containing 4 to 6 per cent ash content ignites rapidly enough and burns well in the Rupamotor. But when the ash content is above that value. say from 8 to 10 per cent on, flame propagation is materially retarded, the finely ground ash dust throwing a veil in front of the ignition. In this respect it acts similar to rock dust which retards or prevents coal dust explosions in a mine. Similar action is found with semi-bituminous coals. Both kinds of coal can be burned completely in the engine if the compression temperature is artificially raised by a small pilot flame, that is to say by an early ignition with gas oil amounting to about 6 or 7 per cent of the heating value of the coal charge per stroke, or by mixing with ignition brown coal. Even damp charcoal or damp peat dust can be burned very well by such secondary heat, whereas a dry charcoal and sufficiently dry peat dust burn without that expedient. Bituminous coal from Upper Silesia containing 16 per cent ash works well in the engine, if 80 per cent of that coal is mixed with 20 per cent of brown coal.

The engine also works very well with ordinary rye flour such as Upper Silesian waste flour which was heretofore sold in flour mills as dog feed. It was used without any preparation just as delivered.

Now to the question where moisture in the powdered coal is necessary in order to obtain good ignition. Up to the present we had always had to endeavor to dry the coal. Never had we to put moisture into the coal in order to obtain better ignition. A certain amount of moisture appears to be good for ignition and at any event does not seem to disturb it, but only in very, very small percentages of the coal used. I cannot imagine any absolutely dry coal. The necessary dryness is found by us by the test that if the coal is compressed by the hand it does not stick together like a snowball. On the contrary, it must, after release from the hand and being dropped on a board, form a cone and resume its original angle of repose. Then it can be emulsified properly with the very small amount of air which is necessary for conveying. Only then can it be sent properly through the narrow ducts, which can be adjusted by the admission valve.

The content of carbon dioxide in the exhaust gases varies of course with the load on the engine. We have, however, not made any analysis with the Orsat apparatus.

Since Rupa engines are to be used in our customer's shop for trials with all sorts of coal, we built at the present time all Rupa engines with the centrifugal conveyor.

The centrifugal conveyors run freely in their tubes and run so fast that the flights are never completely filled with coal powder, and that the conveyors mix the emulsion air with the coal powder.

With regard to the possibility of packing the coal dust tightly the following can be said. In the drawings of the paper one can see between the storage bin and the admission valve (which is in the center of the cylinder) two centrifugal conveyors. One of them carries an excess quantity of powdered coal from the storage bins into the inlet valve. The other centrifugal conveyor takes from that the unconsumed excess, and returns it to the storage bin. This means that a continuous circulation is maintained from the storage bins to the inlet valve and back again. From this circulating stream the inlet valve only

takes what can pass through it depending upon the height of its lift and the time, which quantity corresponds to the load on the engine. The coal powder which has been brought in excess by one centrifugal conveyor can in spite of this fact not pack or be briquetted because the not-consumed excess is always returned by the other centrifugal conveyor to the storage bin.

In the Rupa engine there is no constant relation between coal and combustion air, and therefore also no correct or incorrect ratio. The same is true of the Diesel engine.

The fuel consumption of an internal combustion engine whether operated on oil or on coal depends upon the pressure and temperature at which the fuel is burned. The fuel should of course not burn in the latter part of the expansion stroke.

A question was asked regarding the relation between fineness of grinding and coal consumption per horsepower hour, and also on its effect on the wear of the cylinder and on correct machine operation. These problems will be the topic of doctor dissertations for the next twenty years. It is true that we have investigated many different kinds of powdered coal and that we have reached the technically important goal to make the engine run continuously in practice. But much research work still remains to be done. It is the same with the Diesel engine. Even today certain Spanish oils require detailed research in German Diesel engine factories.

MR. R. J. BENDER (Fuller Lehigh Company, Fullerton, Pa.): Referring to the paper by Dr. Kleinow, I do not think Dr. Fleischmann said anything about the lining of the furnace.

DR. FLEISCHMANN: There is no lining, just the still and the fire arch brake. So far we haven't had any trouble.

MR. R. J. BENDER: How long has this engine been running?

DR. FLEISCHMANN: Two years. The best proof that the locomotive has given satisfaction is that a repeat order of four locomotives has been placed with our company.

MR. R. J. BENDER: There has been no oxidation of the plates, no burning of the steel on account of the combustion?

DR. FLEISCHMANN: I can only say the results seem to prove there has not been any trouble because as a rule the German State Railways are exacting in all their demands. Placing an order for four more locomotives I think speaks for itself. I must confess I am not an authority on the question.

CHAIRMAN ORROK: I will call the gentleman's attention to one point in the paper where it was stated that the flow of coal was so divided up and so split that there was no blowpipe action on the plate, which was the cause of the trouble on the other locomotives which I happen to know he refers to.

MR. R. V. KLEINSCHMIT (Arthur D. Little, Inc., Cambridge, Mass.): It strikes me that although this powdered coal locomotive is extremely interesting, it bears very much the relation to the present type of grate fired locomotive that the first automobile did to the carriage. Without attempting to design the boiler for the service, they have attempted to stick a powdered coal furnace into an ordinary locomotive boiler.

Some very interesting work done several years ago in connection with oil burners leads me to think that possibly another design could be tried with perhaps greater success. This design would consist of a tubular furnace of small diameter, perhaps a foot or so in diameter, lined with refractory extending the full length of the locomotive boiler, and acting essentially as a gas producer, the powdered fuel being mixed with only such air as was necessary to produce carbon monoxide and hydrogen at the front end of the boiler. The front end of the boiler is then an ideal place to take in secondary air in a secondary combustion chamber, and then lead the hot gases back through the boiler.

I hope the interest in this powdered coal boiler will induce someone to try this method of firing.

MR. ALLEN H. BABCOCK (Southern Pacific Company, San Francisco, Cal.): The Southern Pacific Company operates twelve divisions. On ten of them oil is used; on two of them New Mexico coal. The question raised a moment ago about the necessity of lining fire boxes suggests a question to me. Is furnace temperature higher with pulverized fuel than with oil?

Our oil burners produce a blowtorch flame. I am not aware any trouble is caused thereby. I would like to be informed if there is any reason why pulverized solid fuel should act any differently than pulverized liquid fuel on the plates.

CHAIRMAN ORROK: Do you heat your oil before you burn it in the burners?

MR. ALLEN H. BABCOCK: The only necessity for heating the oil as far as I know is to make it flow freely to the burner and to assist in atomization, which does not require a great deal of heat, unless the oil has high viscosity.

MR. MORTIMER SILVERMAN (Boston & Maine Railroad, Boston, Mass.): The question I would like to ask is whether or not any trouble has existed with reference to the moisture getting into the tender and preventing the feed of the powdered fuel? Also, whether or not there has been any attempt made to actually pulverize the fuel on the tender itself rather than the separate pulverizing plan?

CHAIRMAN ORROK: Now I will ask Dr. Fleischmann to close on this paper.

DR. FLEISCHMANN: I would like to answer Mr. Kleinschmit first, but I would like to consider it from a different point of view. The idea of the German officials was to make use of the old machine with as little change as possible. It was specifically stated that the old boilers had to be used as far as

possible. That is the reason you make this comparison between the carriage and the automobile. I am a little bit prejudiced. I am an electrical engineer and I would like to see the electric locomotive.

As Mr. Babcock has already remarked, of course there is no difference between the cutting action of the powdered coal and oil because both, if they are entirely burned, leave only gas. I don't think that gas even at very high velocity produces erosion as long as we have no sand blast action of unburned particles.

As to the third question, Professor Rosin was kind enough to tell me, as far as I understood, that the German authorities are studying this question. I am talking more from a general point of engineering. The new locomotive carries additional weight because it has the coal plus the apparatus on the machine. In Germany working under much more limited conditions than you are here because our maximum is limited to twenty tons; on the idlers, fourteen tons. Naturally, we have to do everything to keep our weight down. I do not think the whole mill could be carried by the tender; otherwise it means a loss of effective drawbar pull.

CHAIRMAN ORROK: It appears that Mr. Babcock and Dr. Fleischmann have brought up a very interesting point. What is it that cuts the steel sides of a boiler tube or a boiler furnace when a flame plays on it? We learned quite early in the game that it did not do to have a blowpipe flame play up against a water tube. We found in almost every case, if you got your blowpipe flame just right and the inner cone of the flame against the tube, your tube got red hot. It soon opened out and that was the end of the tube. Probably the same thing happens with the flame from powdered coal, or with the flame from oil. The reason Mr. Babcock does not get it is because he has a boiler where the oil gets very hot in the burner temperature. He gets good atomization. He does not get that in a coal flame. He would if the oil were cooler. Or you might get it out of the powdered coal flame with the old-fashioned burner. This new burner with 50 orifices must mix up that flame very much and prevent any single point of the flame playing on the fire box.

MR. ALLEN H. BABCOCK: We find under stationary boilers that it is very easy to blister plates if we do not distribute the air properly and if we do not provide enough combustion space. The nearer you can make your flame a soft, rolling flame, the less the action will be on the boiler plates. Therefore, what is a perfectly proper setting with a very ordinary type of boiler can be made to give very good results, or if the air distribution is not properly regulated, it can be very destructive. I do not think it is at all a question of blowpipe action; but is wholly a question of how best to liberate a given number of heat units per unit of time in a given space, and at the same time to avoid local heating.

MR. J. M. NICHOLSON (A. T. & S. F. Railway Company, Topeka, Kans.): The question was raised by a representative of the Southern Pacific with regard to this furnace line.

MR. ALLEN H. BABCOCK: I do not think I raised that question.

MR. J. M. NICHOLSON: The answer to that I think is this; You are working with a different proposition in using pulverized coal than using an oil burner. Your oil burner sprays oil in the front or back of the box, while the pulverized coal comes in burners that are opposite, and the flame centers between the two burners rather than against the surface in which the fuel is thrown. In this connection I might state the Santa Fé have a Mikado equipped for burning pulverized coal. They have had it for about a year and a half. The locomotive had 59,600 tractive force and was tested in through-freight service. We put the coal in the front of the box and we put it in the back of the box. We played burners against each other. We had to go to rates of about 6000 pounds of coal per hour in order to get the rates that were required to get the maximum horsepower out of that boiler. We had to have furnace liners; we could not get along without them.

We could not get down as low with our burner arrangement as was the case in this boiler sketched out, for the reason that we had a trailer. The height was limited there.

I think the answer to being able to get along without furnace liners is that you fellows are putting two burners against each other in the short space, which we do not do at all.

DR. FLEISCHMANN: May I say in addition to this, that with induced flow of fuel the fuel supplied with the one nozzle is cut off, but the air supply remains. So that the two streams, a current of air, meets the current of air plus fuel still in the middle, so even then there is no touching of the flame on one side.

CHAIRMAN ORROK: We are open for discussion on one more paper, that of Dr. Blythe on "Pulverized Fuel and Its Various Fields of Application." I am a little bit astonished at some of the statements he has made in that paper, particularly that the stoker has not given as good a service as it might. I think that is rather odd because Mr. Pearce at his Battersea Station is just putting in stokers, each one of which will burn around 57,000 pounds of coal per hour, and I understand he has a guaranteed boiler efficiency over a year of 88 per cent.

MR. EDWARD RAHM: In Dr. Blythe's paper he lays considerable stress on the turbulent type burner. This is one way of looking at the problem. We agree with him that you must have turbulency in order to promote the intimate contact of oxygen and carbon but we think that he should have mentioned the item of fineness of grinding. The finer you grind, the less the need of turbulency. It is evident that the finer the pulverization, the greater the number of carbon surfaces exposed to the action of the oxygen, thus producing complete combustion in the least time. Fine grinding is really of more importance than turbulency. The degree of fineness of pulverization is really a function of the volume of the combustion chamber of the rapidity of flame propagation, and of the efficiency of heat release. We would submit the thought that Mr. Blythe has not given the fine pulverization the degree of importance that we think it should have.

THE THERMODYNAMICS OF THE COMBUSTION OF POWDERED COAL

By P. Rosin, Dr. Ing.

Mining Academy of Freiberg, Germany

This paper deals with the liberation of heat in a combustion space and with the factors on which it depends. This conception of heat liberation, if properly applied, is an important thermodynamic quantity which represents the intensity of combustion. It is measured by the number of calories developed per cubic meter and hour ($cal/m^3 \times h$) or ($B.t.u/ ft^3 \times h$) during complete and perfect combustion including the heat delivery by preheating. Complete combustion signifies that the final products are carbon dioxide and water. Perfect combustion requires that no unconsumed dust shall leave the combustion chamber or be deposited in it prematurely.

In the year 1925 I was the first to develop the rate of heat liberation of combustion spaces on the basis of hydrodynamic facts[1]

$$B = \frac{3600 \times H_u}{V_T \times Z} \text{ calories per cubic meter per hour.} \tag{1}$$

B means the heat liberation; H_u is the lower heating value of the fuel in kilogram calories per kilogram. V_T is the volume of the products of combustion in cubic meters developed from one kilogram of fuel measured at the absolute temperature of the combustion space. Z is the combustion time of the coarsest dust grains in seconds. If V_o equals the gas volume liberated from one kilogram of fuel under standard conditions (0°C, 760 mm. Hg.)

$$V_T = V_o \frac{T}{273} \tag{2}$$

$$B = \frac{3600 \times H_u \times 273}{V_o \times T \times Z} \tag{3}$$

$$= 982{,}000 \times \frac{H_u}{V_o} \times \frac{1}{T} \times \frac{1}{Z} \text{ kilogram calories per cubic meter per hour.}$$

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[1] See *Braunkohle*, 1925, No. 11, p. 241.

In 1926 I succeeded in proving[2] that the quotient H_u/V_o, i.e., the ratio of the lower heating value to flue gas volume under standard conditions follows a law for all fuels as indicated in Table I. For that reason the actual value of the fraction $H_u \div V_o$ can be arbitrarily influenced only by the amount of excess air. Increased excess air increases the gas volume but also lowers the tempera-

TABLE I

RELATIONS BETWEEN WASTE GAS VOLUME V_o AND HEAT VALUE H_u

Coal	$V_o = \frac{0.89}{1000} H_u + 1.65$ nm³ per Kg.
Oil	$= \frac{1\ 11}{1000} H_u$ nm³ per Kg.
Gas $H_u < 3000$	$= \frac{0.725}{1000} H_u + 1.0$ nm³ per nm³
$H_u > 3000$	$= \frac{1\ 14}{1000} H_u + 0.25$ nm³ per nm³

TABLE II

DEPENDENCE OF RATE OF HEAT LIBERATION ON THE EXCESS OF AIR

		EXCESS OF AIR PER CENT				
		0	25	50	75	100
V_o	nm³/kg.	7.9	9.75	11.7	13.55	15.45
Heat content i $= H_u/V_o$	kcal/nm³	890	720	600	520	455
Combustion temperature	degrees C.	2,040°	1,800°	1,590°	1,430°	1,280°
T	degrees abs.	2,313°	2,073°	1,863°	1,703°	1,553°
$V_o.T$	—	18,250	20,200	21,800	23,100	24,000
Combustion rate	per cent	100	90	84	79	76

ture of the combustion space unless the combustion air is highly preheated. Table II shows that the product $V_o \times T$ grows with increasing excess air so that high excess air always is equivalent to a reduction of the rate of heat liberation (Fig. 1). If we neglect the variations caused by varying excess air, the value of the quotient

[2] *Zeitschrift des Vereins Deutscher Ingenieur*, 1927, No. 12, p. 383.

(heating value divided by volume of the product of combustion) can be considered constant for the following investigations and we obtain equation (4).

$$(4) \quad B = \text{constant} \times \frac{1}{T} \times \frac{1}{Z} \text{ kilogram calories per cubic meter per hour.}$$

The numerical value of the constant can easily be calculated for any coal and air excess since the quotient $H_u \div V_o$ can be taken from diagram, Figure 2, for all fuels and excess air. With a theoretical

TABLE III

BURNING TIME AND RATE OF HEAT LIBERATION

BURNING TIME Z sec.	RATE OF HEAT LIBERATION B kcal/m³.h	STEAM PRODUCTION kg/m³.h	NECESSARY FURNACE VOLUME m³		RATIO OF THE HEATING SURFACE TO THE FURNACE VOLUME m²/m³	
			43 kg/m².h	100 kg/m².h	43 kg/m².h	100 kg/m².h
4	84,500	109	396	922	2.5	1.1
3	112,500	145	297	691	3.4	1.4
2	169,000	218	198	461	5.1	2.2
1	338,000	435	99	230	10	4.4
0.6	564,000	727	59	138	17	7.3
0.5	676,000	873	50	115	20	8.7
0.4	845,000	1,090	40	92	25	11.0
0.3	1,125,000	1,450	30	69	34	14.0
0.2	1,690,000	2,180	20	46	51	22.0
0.1	3,380,000	4,350	10	23	101	44.0

quantity of air and the limiting temperature we obtain from equation (1) equation (5),

$$(5) \quad B = \frac{338{,}000}{Z} \text{ kilogram calories per cubic meter per hour.}$$

which shows the heat liberation as a hyperbolic function of time.

The problem of rate of heat liberation is therefore a velocity problem and its characteristic feature is the time in which combustion is completed in the combustion chamber. But the combustion process is not a simple event. It is a collective term of thermo-physical, thermo-chemical, and thermo-dynamic events which occur partly in parallel and partly in series and which in their relative course and in their mutual velocities are subjected to great variation.

Table III will show the influence of the combustion time by a practical example. It contains for a steam boiler of 1000 square meters surface the rate of heat liberation, the steam generation per cubic meter of combustion space, the amount of necessary combustion volume for a specific evaporation of 43 and 100 kilograms per square meter per hour, and the ratio of heating surface to combustion volume for these two rates of heat liberation, or both rates of steam generation. In connection here it should be remarked that the longest combusion time of the coarsest grains of ordinary pulverized fuel combustion systems does not exceed four seconds. As

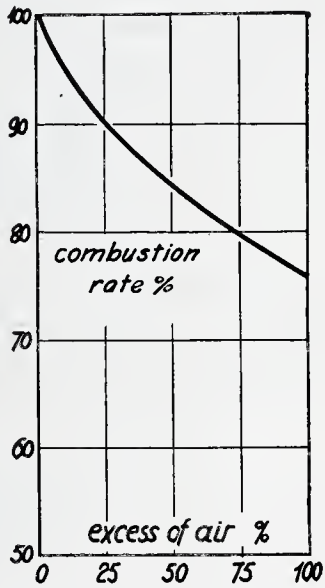

FIG. 1. RELATION BETWEEN COMBUSTION RATE AND EXCESS OF AIR

an illustration, it may be said that the rate of heat liberation of most combustion spaces of power plants fired with powdered coal lies between one hundred thousand and two hundred thousand calories per cubic meter and hour (11,000 and 22,000 B.t.u./ft^3 $\times$ h) corresponding to a maximum burning time of 1.5 to 3.6 seconds. In locomotives the ratio of heating surface to combustion space has the value of 25 to 30 and powdered coal locomotives must therefore have a heat liberation of 800,000 to 1,000,000 calories per cubic meter for a rate of evaporation of 43 kilograms per square meter and hour, to which corresponds a maximum combustion time of 0.4 to 0.3 second. The German State Railways demand for a powdered coal locomotive

a continuous evaporation of 65 kilograms per square meter per hour. With an efficiency of 70 per cent the necessary heat liberation rises in this case even to 2,000,000 calories per cubic meter (220,000 B.t.u. per cubic foot), so that the longest combustion time for theoretical combustion must not exceed 0.17 second.

In gas firing it is possible to develop 3,000,000 to 4,000,000 calories per cubic meter of combustion space per hour. It will be realized that the rate of heat liberation of stationary power plant boilers is rather low in comparison wih these figures. At that, we try on one hand, to save heating surface and boiler house space by means of high rates of evaporation; on the other hand, there corresponds, as the table shows, a combustion space of at least 500 to 600 cubic meters per 1000 square meters of boiler surface with at least 100 tons per hour of steam generation, with the heat liberation which is used today. From that, the necessity of increasing the rate of heat liberation becomes clear. But since the rate of heat liberation is inversely proportional to the combustion time, we must proceed on the path of reducing the combustion time.

But what is the meaning of the term combustion time? Again we must procure a clear definition of the term which we wish to improve. The term combustion time is only the expression of a collective function of many, partly independent, partly inter-connected, variables; a collective term which has in it the velocity of many physical and chemical reactions, which cannot be expressed mathematically and have in fact not yet been investigated chemically. But even if we cannot look into the manifold details of this phenomenon, we can pick out the three important influences, upon which the combustion time depends and their influences can be investigated at least qualitatively. These three factors are: Fineness of powder (St), Temperature (T), and the entirety of the hydrodynamic and aerodynamic processes in the combustion chamber (Ae). The combustion time therefore can be generally expressed as a function of these three variables.

$$1/Z = f(St, T, Ae). \tag{7}$$

and also the rate of heat liberation from equation (4)

$$B = \text{constant } f(St, T, Ae). \tag{8}$$

FINENESS OF POWDER

It is quite evident that the combustion time becomes less as the size of grain decreases. The relation between combustion time and size of grain can, according to my investigations, be expressed as the equation of a general hyperbola of the form.

$$Z = \frac{C}{\left(\frac{F}{G}\right)^m} \text{ seconds} \tag{9}$$

In which Z is the combustion time in seconds; C is a constant; F the geometric surface of the dust particle in square meters. G is the weight of the particle in milligrams, and m is an exponent.

For the numerical evaluation of this equation the simplifying assumption must be made that the particle is either a cube or a sphere. With length of a side of a cube of "a" millimeter and a specific gravity of γ, we have

$$\frac{F}{G} = \frac{6}{\gamma\, a} \tag{10}$$

Since γ can be considered a constant for a given kind of coal we have

$$Z = \text{constant} \times a^m \tag{11}$$

which is the combustion time as an exponential function of the length of cube side or of the diameter and in which

$$\text{Constant} = C\ (\gamma/6)^m$$

In this equation Z appears only as a function of the length of the side of the cube, whereas we saw in equation (7) that it is also a function of the temperature and of the aerodynamic condition.

It is immediately clear that the influences of the two last named variables must be contained in the value of the exponent, m, so that the latter must be considered a logarithmic function of temperature. Equation 11 can therefore have a constant exponent only for the same coal and in the strictly constant values of T and Ae. Just as soon as temperature and turbulence change in the combustion space, the exponent is also changed and the relation between the combustion time and the size of the particle is expressed by a different hyperbola. Unfortunately, insufficient attention has been paid to these relations,

with the result that the numerical values for equation (9) previously obtained by me experimentally[3] for powdered German brown coal at 1300°C., with C = 1000 and m = 1.8 have been generalized in literature, have been compared with other values and have been transferred to different conditions, which fact has led to errors.

In addition to the three above-named factors the chemical composition and above all the quantity and heating value of the volatile matter exerts an influence on the combustion time. It is a well-known fact that powder made from semi-bituminous coal requires longer combustion time than that of bituminous coals. These

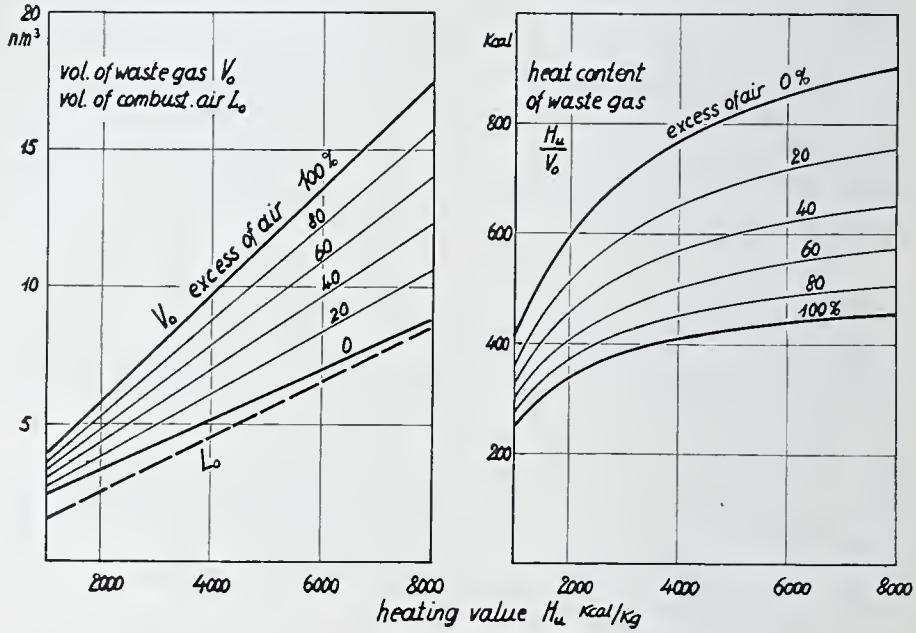

FIG. 2. VOLUME AND HEAT CONTENT OF WASTE GAS

influences can probably be expressed by the value of the constant C of equation (11) which contains also the specific gravity, so that this constant expresses the influences of the kind of coal, whereas the exponent m expresses the relation as a function of the condition in the combustion space. It is readily seen how far we are even today from a quantitative application of this equation in practical cases.

Only one important question can be answered today, namely to what extent can the heat liberation in the combustion space be raised by an increase in fineness. To that end, equation (11) is

[3] *Braunkohle*, 1925, No. 11, p. 244.

sufficient, if we make the reservation that by the simple increase in fineness, temperature and turbulence in the combustion space shall not be changed. Then the numerical value of the constant and the exponent in equation (11) do not matter for the interrelations between size of dust grain and combustion time, as long as they are of practical size. For that reason I will use the brown coal values which were experimentally determined by me and were confirmed by other investigators also for bituminous coal.

C = 1,000 and m = 1.8. The analysis will be based on a bituminous coal of 7000 calories per kilogram and a specific gravity $\gamma = 1.2$ which is burned in powder form with excess air of n = 1.25.

TABLE IV

RELATION BETWEEN RATE OF HEAT LIBERATION AND SIZE OF COAL PARTICLES

SIDE OF CUBE μ	HEAT LIBERATION kcal/m³.h	SIDE OF CUBE μ	HEAT LIBERATION kcal/m³.h
10	24,700,000	110	330,000
20	7,100,000	120	282,000
30	3,420,000	130	242,500
40	2,035,000	140	213,500
50	1,362,000	150	188,500
60	983,000	160	168,000
70	744,000	170	150,500
80	585,000	180	136,000
90	473,000	190	122,500
100	391,000	200	112,500

The rate of heat liberation is for this case according to equations (3) and (11).

$$B = 982{,}000 \frac{7000}{9.75} \times (1/273) \times (1/Z) \tag{12}$$

$$= \frac{340{,}000}{55\ a\ 1.8} = \frac{6200}{a\ 1.8}\ \text{K.cal./m}^3 \times \text{hr.}$$

The length of side of the coarsest dust particles is determined by screening. In a modern power plant boiler any dust can be considered as ready for combustion if it leaves no residue on the sieve with 900 meshes per square centimeter (Tyler screen No. 65) that is to say if the largest dimension of the coarsest grain does not exceed 0.20 mm. (200 microns).

Table IV shows the evaluation of equation (12) for a length of side of 10 to 200 mu. It confirms that the selected values correspond to present day conditions of powdered coal boilers in which the powder leaves no residue on German screen No. 30 (Tyler No. 65), and in which rates of heat liberation between 100,000 and 200,000 calories per cubic meter an hour (11,000 and 22,000 B.t.u./cu. ft. $\times$ h) are the rule.

The tabulation also shows that in agreement with the nature of an exponential function the increase in rate of heat liberation becomes faster and faster with smaller length of side of the cube. But it is questionable whether for smaller lengths of sides of the cube the empirically found law is still valid or whether the limits have not already been exceeded. Each relation determined by test or hypothesis agrees with natural phenomena only over a certain range. Outside of the limit of this range the coincidence of the curve is no longer sufficient to represent actual conditions. The empirical or theoretical curve then gives no longer a picture of the true condition. The tabulation shows that beginning with a certain fineness the rate of heat liberation can be raised as high as we please, without bringing in the requirement of an especially great increase in fineness. But this means that no longer does any relation between fineness and rate of heat liberation exist, and that vice versa an increase of fineness alone has no influence any more on the rate of heat liberation. In other words: from a certain fineness onward we can obtain any desired rate of heat liberation as long as the other two variables—namely, temperature and turbulence—permit. The question then is where the limits of fineness lie for practical application. According to the tabulation the two million limit is exceeded only at 40 mu that is to say with a length of side which lies below the width of mesh of the German screen No. 100 with 10,000 meshes per square centimeter that is to say below that of the United States screen No. 325.

It is quite evident that such fine grinding cannot be economically considered for boiler firing. But it is not necessary that all of the dust pass through the screen without residue; on the contrary it is permissible to work with a certain residue and in consequence with a loss of potential heat, if thereby we obtain this high rate of heat liberation and if the loss caused by incomplete combustion is balanced by the lower first cost due to the higher rate of heat liberation. This method of operation is of course predicated upon the condition that the unconsumed particles will not cause trouble and interruption of

operation by slag deposits and "birds-nests." It is also necessary to be quite clear concerning the magnitude of the loss which is caused by the fact that coal dust contains particles which have a longer combustion time than corresponds to the rate of heat liberation.

This can be ascertained nowadays on the basis of research work concerning the composition of powdered coal which I have carried on

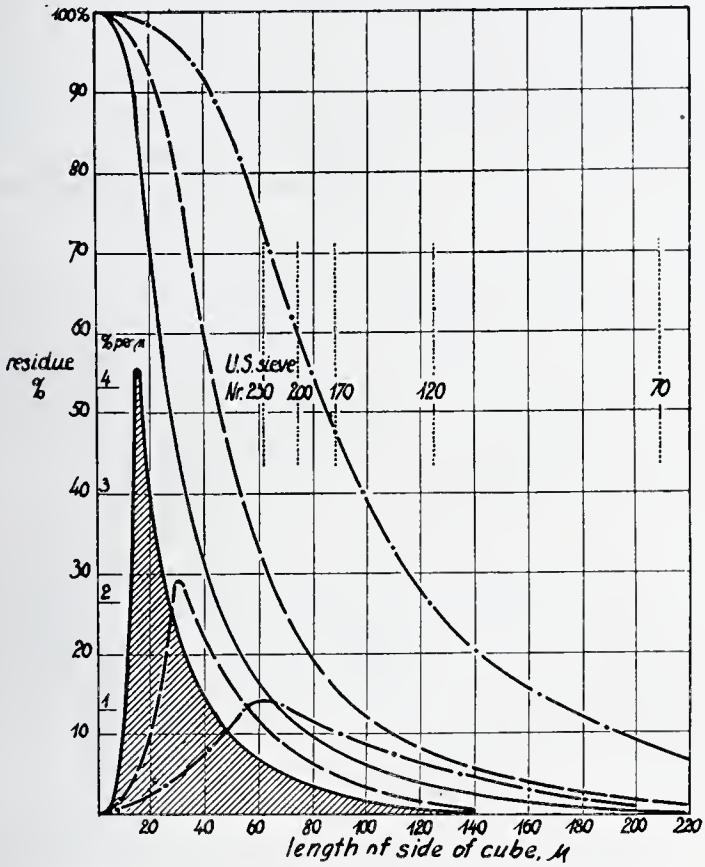

FIG. 3. CHARACTERISTIC AND DISTRIBUTION CURVES OF PULVERIZED COAL

together with Rammler for the German State Coal Council.[4] The important results of this investigation can be summarized as follows. (See Figure 3):

(1) The composition of any coal dust can be represented in the form of a characteristic, the shape of which depends only upon the absolute fineness of the dust and is practically independent of the kind of pulverizer and kind of coal.

[4] *Zeitschrift des Vereins Deutscher Ingenieure*, 1927, No. 1, p. 1.

(2) The distribution of the grain sizes in a coal dust is given by the differential curve derived from the characteristic. These distribution curves have the character of probability lines. The ordinate of a point indicates the change in per cent of the total quantity which is caused by a change of fineness of 1 micron. The integral of the surface must therefore be 100 per cent. With increasing absolute fineness the preferred size of grain is not only displaced farther into the region of finest dust but its weight proportion of the total quantity rises rapidly.

From this follows for the heat liberation the very remarkable fact that with the usual fineness of 10 to 20 per cent residue on the screen of 4900 meshes per square centimeter (U. S. Screen No. 170), the maximum fraction is of a size the combustion time of which is in any event so short that any desired rate of heat liberation can be attained. Only the comparatively small number of particles with greater length of side are not entirely consumed in the furnace working with a very high rate of heat liberation, but still this whole amount should not be booked as a loss, because they participate in the combustion in the ratio of their combustion time. It is thus only a question of desired efficiency just what losses of unconsumed combustile shall be permitted.

In order to determine the actual size of this loss, we must make an assumption concerning the nature of combustion of the dust particles, that is to say concerning the relation between amount burned and time. Experiments on this relation do not exist up to the present time. We only know the limiting values, namely, that of a particle with a combustion time Z

at the time O	0 per cent and
at the time Z	100 per cent have been burned.

As far as the nature of the function between these two limits is concerned we can make qualitative deductions only.

In the following reasoning (see Figure 4) let

Z = time available for combustion

a = length of side or diameter of a particle of such a size that it will just burn completely in that time.

Z_i = combustion time at any other size of particle with the length of side $a_i > a$ ($Z_i > Z$).

a_n = the greatest length of side or diameter existing in the coal dust.

We shall consider a single particle with the length of side a_i. The simplest assumption is that it burns away proportionally to the time, that is to say that the weight as a function of time is represented by the straight line AB. Surely this assumption does not correspond to the actual combustion events which we will see later are probably more correctly represented by the dotted curve. But we can base our calculations on the linear function for the reason that (as becomes clear from the relative shape of the two lines) it furnishes too high values of unconsumed combustibles and that our calculated results are therefore less favorable than they are in practice. If thus this limit case calculation furnishes a tolerable loss, the actual loss must be less in practice.

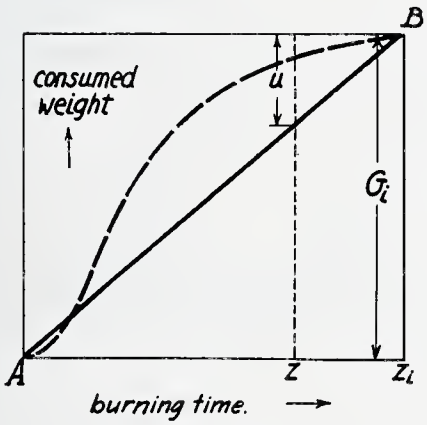

FIG. 4. RATE OF DUST COMBUSTION

If G_i is the weight of the dust particle with the length of side a_i and if u is the unconsumed combustible at time Z, then the illustration shows that

$$u = G_i \times \frac{Z_i - Z}{Z_i} = G_i - G_i \times \frac{Z}{Z_i} \tag{13}$$

Now actually the dust consists of the sum of steadily merging classes of particles with the length of side $a_1, a_2, a_3, \ldots\ldots\ldots a_i \ldots\ldots\ldots a_{n-1}, a_n$ which respectively are successfully contained in it with the proportions r_1, r_2, etc., in such a manner that the $\sum_{a=o}^{a_n} r_i = 1$ which equals

the total quantity of dust. If equation (13) is applied to particles of size r_i then its unconsumed portion in the available time Z is

$$u_i = r_i - r_i \frac{Z}{Z_i} \tag{14}$$

Within the time Z all those particles $\sum_{a=o}^{a} r_i = D_a$ burn, the largest dimensions of which is not greater than a. Those of larger size leave an unconsumed residue which is in each case determined by equation (14). The whole of the unconsumed fuel is then

$$\Sigma u_i = \sum_{a}^{a_n} r_i - Z \sum_{a}^{a_n} \frac{r_i}{Z_i} \tag{15}$$

But $\sum_{a}^{a_n} r_i$ is the total unconsumed residue of R_a of the dust on the screen with width of mesh "a," therefore

$$U = R_a - Z \sum_{a}^{a_n} \frac{r_i}{Z_i} \tag{16}$$

Thus it is possible to determine for any desired burning time Z the fraction of unconsumed particles by finding the greatest particle dimension which corresponds to this combustion time from Figure 5, and then determining from the dust characteristics that residue which corresponds to a screen of this maximum diameter of dust particle. The sum of the quotients can easily be computed from such a diagram in which the dust characteristic and combustion time have been plotted as functions of the side of the dust particle cube.

From equation (16) it is not only possible to determine for any desired combustion time and for any given dust the fraction of unconsumed fuel, but we can also find the curve of the entire combustion process by successively varying the combustion time from Z_o to Z_n and by substituting in each case, depending upon the value of Z, the residue R and the lower limit of the sum of the length of sides of the particles. By this method the combustion characteristic of the illustration was determined. It enables us to find the unconsumed fuel for any desired combustion time.

The illustration is valid for a powdered Westphalian, bituminous coal which was ground on a tube mill. It will be seen from the illustration that for instance with a combustion time of one second

corresponding to a rate of heat liberation of 340,000 calories per cubic meter per hour the loss in unconsumed combustibles equals four per cent, whereas for a rate of heat liberation of 1,000,000 the loss amounts of approximately 11.5 per cent. Furthermore it will be seen that for obtaining higher rates of heat liberation we must grind more finely for the purpose of having bearable losses of unconsumed fuel. It may again be mentioned that this calculation most certainly furnishes values which are too high.

The thus obtained combustion line is based on the assumption that loss of weight by combustion of the particle is proportional to

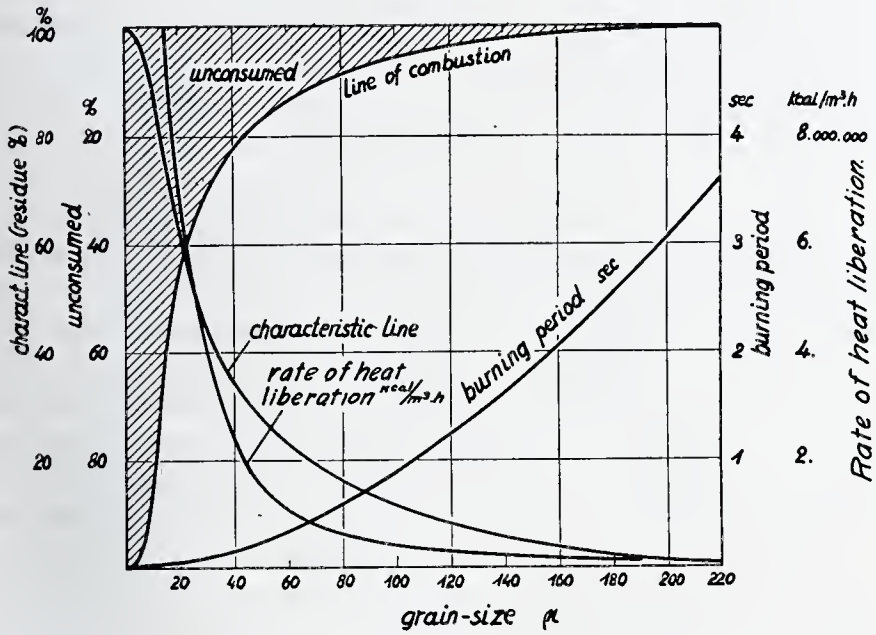

FIG. 5. CHARACTERISTICS OF DUST COMBUSTION

time which assumption is most certainly not correct, at least during the early stages of the combustion. For if we follow the usual view about ignition and combustion of powdered coal we find first a period of degasification; then the solid particles are ignited and ignite in turn the liberated gases which burn with high velocity and high temperature and thereby in turn contribute to quick combustion of the degasified residue. But if we study the combustion curve carefully we are necessarily led to the conclusion that the usual view cannot be right. In his book on "Fuels and Combustion" Aufhäuser defines true combustion as the elementary oxidation of the water-gas

components CO and H_2. But since these are not present in the natural fuel at the beginning, combustion proper must be preceded by a period of converting these fuels into readiness for combustion, and this period must consist in a pyrogenic decomposition of the fuel and additive oxidation or peroxidation, which from a certain acceleration on represents ignition. So the combustion process, which appears to us to be a single continuous phenomenon really is subdivided into two very different sections, namely into conversion for readiness of combustion, and combustion proper. The conversion itself again consists of the three processes of absorption of heat, pyrogenic decomposition with volatization of the volatile matter and additive oxidation which, in its accelerated phase is the ignition. But we must not imagine that all of these processes occur one after another with well marked divisions with regard to time. They do not do that even for a single particle of coal dust. As soon as the latter enters into the combustion space it absorbs heat. On account of the low thermal conductivity of coal the temperature on the outside of the particle rises quickly and the surface undergoes pyrogenic decomposition, during which period gases are liberated. But simultaneously the adsorption of oxygen and auto-oxidation begin, both of which contribute towards the rapid increase in temperature as a result of which the ignition sets in. But while these processes go on at the surface, heat conduction to the interior is continued and there in a progressive manner the completion of the pyrogenic decomposition takes place. On the basis of the combustion line we can answer the question whether a complete or almost complete degasification takes place *ahead* of the ignition of the coal particles. The above described transformation into readiness for combustion is a process which, depending mainly on the thermal conductivity of the fuel requires a definite time. As a consequence of this fact, we observe in an even more pronounced manner than with solid injection Diesel Engines or in oil furnaces, the phenomenon of delayed ignition (time-lag) which was first investigated by Hawkes in Diesel Engines. This delayed ignition is still greater in the combustion of powdered coal first because the fuel particles, the largest diameter of which in Diesel Engines is only 10 mu and in oil firing is approximately 20 mu, rises up to 200 mu in coal dust. But since on the other hand the maximum of the grain distribution curve with finely ground dust lies between 10 and 20 mu, the order of magnitude of ignition delay observed with Diesel Engines can be used for this case.

The best work on delayed combustion in solid injection Diesel Engines was done by Neumann[5] who investigated the interrelations between temperature, pressure and turbulence. Similarly accurate experimental data are at the present time not in existence for powdered coal combustion, the research work of Nusselt not having been finished as yet. I have, however, from many observations of powdered coal combustion in actual practice determined ignition delay to be approximately 0.05 to 0.2 seconds, restricted to that range by effects which will be discussed later on. The figures show however that, just as in Diesel Engines evaporation of the oil during the delayed ignition can occur only to a very small extent, just so degasification of the dust ahead of the ignition reaches only a very low value and must be limited to the surface. For the duration of the delayed ignition is much too short to have pyrogenic decomposition occur to a noteworthy degree in consideration of the poor heat conductivity of the coal.

The magnitude of the time-lag is decisive for the shape of the beginning of the combustion line. Since for high combustion rates only fractions of a second are available for combustion, it is easily recognized that great importance must be attached to the ignition delay and to the means of reducing it. Especially in locomotive fireboxes, in which heat is liberated at rates between 1 and 2 millions of calories, the ignition delay must not amount to more than a few hundredths of a second, otherwise the main combustion takes place immediately in front of, and in the tubes, and causes the sufficiently known difficulties of "honeycombs" or "birds-nests."

Therefore, shortening of the ignition delay becomes a most important problem in curtailing the combustion period, and the means for this will be discussed in the following:

INFLUENCE OF TEMPERATURE OF IGNITION DELAY AND COMBUSTION TIME

The relation between rate of heat liberation and temperature is a double one, a direct one and an indirect one. Equation (3) for heat liberation

$$B = \frac{\text{Const} \times H_u}{Z} \times \frac{1}{V_o T} \text{ Kcal/m}^3\text{h}$$

[5] *Zeitschrift des Vereins Deutscher Ingenieure*, 1926, No. 32, p. 1071.

shows in the first place that with dropping furnace temperature, the rate of heat liberation can be increased for the reason that the flue gas volume $V_o.T.$ decreases.

On the other hand

$$\frac{1}{Z} = f\ (St,\ T,\ Ae)$$

is a partial function of the temperature in the sense that with increasing temperature, the combustion time drops so that the

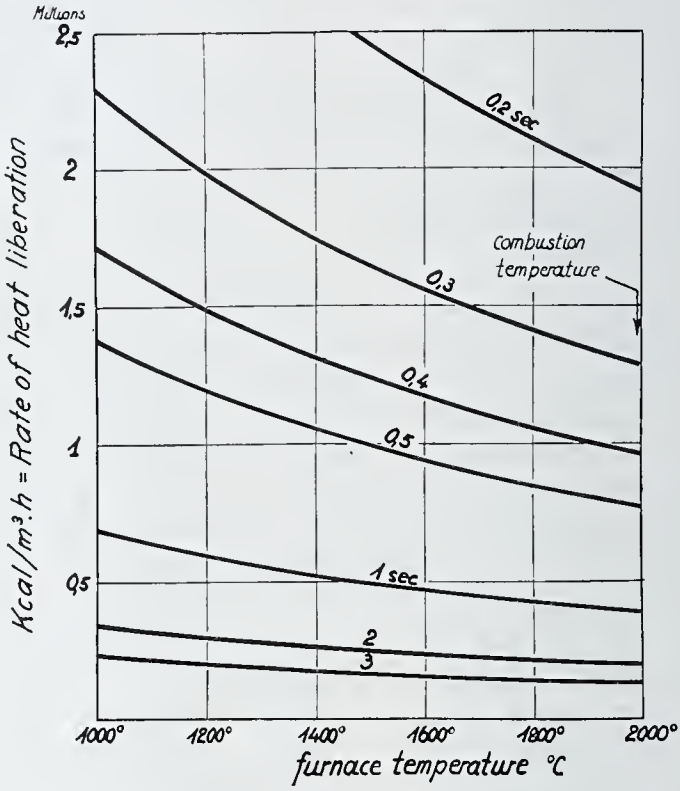

FIG. 6. RATE OF HEAT LIBERATION AS A FUNCTION OF FURNACE TEMPERATURE

heat liberation rises, because at high temperatures the reactions of transformation and combustion take place with greater velocity. Both influences of temperature therefore counteract each other in a certain sense, but not to a point of balance. For that temperature which determines the volume is the sensible mean temperature of the gas-mass in the combustion chamber. On the other hand, the temperature which determines the reaction-velocity is that of the

coal dust—or gas particle or rather that of the reacting limit-layer. The two are different. The relation between rate of heat liberation (furnace load) and temperature is a simple hyperbolic function according to Figure 6 in which it is shown for different combustion periods. One recognizes the strong influence of the mean gas-temperature on the rate of heat liberation of a combustion chamber. As an example, let us consider a combustion time of Z = 0.5 second. One can imagine that combustion takes place in a combustion chamber of theoretical limit temperature, and that the gases then enter into the heat transfer chamber where they give up heat to the heating surfaces of the boiler. In this case which corresponds to the early days of dust-firing with its almost adiabatic un-cooled combustion chambers, and which even to-day is necessary in metallurgical furnaces, the greatest theoretical heat liberation is 680,000 calories per cubic meter per hour. If, on the contrary, combustion takes place in a combustion chamber with cooled walls, in such a manner that the flame gives up its heat immediately to the heating-surfaces, that therefore combustion and heat transfer chamber are identical in such a way that the average gas-temperature is only 1200°, a heat liberation of 1,200,000 calories per cubic meter per hour can be attained. The illustration (Fig. 6) is designed for bituminous coal of 7000 calories per kilogram burned with the theoretical amount of air. But the curves are drawn with due regard to dissociation, which lowers the otherwise attainable limit-temperature by about 200°. This influence of the dissociation raises the greatest possible rate of heat liberation from 680,000 to 770,000, which is 13 per cent.

The illustration teaches another important lesson. The increase of combustion rate obtained by lowering the temperature, is the higher the shorter the combustion time is. Whilst with Z = 2.0 seconds between 1600° and 1200°, only an increase of 64,000 calories is obtained, with Z = 0.5 second that increase is 250,000 calories with the same interval of temperature. Since, in addition, the retarding influence of low temperature is less noticed in the reaction-velocity of fine dust with short burning periods, the lowering of temperature is of primary importance for greater degrees of fineness.

The lowering of the gas-temperature must be the result of direct heat transfer to the heating surfaces of the boiler, and all means for accelerating heat-transfer are of greatest importance. But the effectiveness of this lowering the temperature reaches a limit at the point where diminishing reaction-velocity causes prolongation of the

burning period, which counterbalances the volume-influence. In normal powdered coal furnaces there exists, therefore, a certain equilibrium-temperature, corresponding to a maximum rate of heat liberation which may be characterized by the statement that the temperature is still high enough to keep up sufficient transformation and combustion velocity but is still low enough to obtain an increase of heat liberation by volume-contraction.

In former days the opinion used to be that high rates of heat liberation could only be obtained by highest possible furnace-temperatures, because engineers tried to obtain acceleration of reaction by means of high temperatures, and took no notice whatsoever of the influence of lowering the temperature on the combustion rate. In this attempt the well-known difficulties with refractory material were also encountered for the overcoming of which a huge amount of work was carried out. But the problem is not to keep the temperature in the furnace as high as possible, but to lower it as far as possible, and in spite of this not to diminish the reaction-velocity.

The influence of temperature on the transformation and combustion velocities of powdered coal has not been yet investigated; for a given fineness, it will be very different depending upon the kind of coal. Experimental research of this problem is very difficult, because it is a matter of reactions of two different phases, which are always carried out in a surface, and the velocity of which is determined not so much by the medium temperature of the combustion product but rather by the instantaneous temperature of this limit-layer itself. From this it will be seen that combustion always takes place almost at the theoretical limit temperature, that is to say, independently of the temperature of the furnace, whilst the giving off of heat to the surrounding parts takes place immediately afterwards, but still only as secondary process after a short interval of time. Therefore the gas-temperature of the furnace has less influence on combustion than on conversion for combustion readiness. Adsorption and auto-oxidation, during conversion, are also exothermic processes, which accelerate their own velocity by means of the heat they themselves develop. But the heating of the fuel, the starting of the conversion is exclusively a heat-consuming process, the velocity of which depends on all determining factors for transfer of heat, but especially on difference of temperature. Therefore it is clear that above everything the amount of ignition delay is determined by the furnace temperature. With this, the problem is

clearly pointed out. We must lower the gas-temperature in the furnace as far as possible by directly giving off heat, but in spite of this not influence the velocity of conversion. For this problem exist different solutions. The first and most usual one consists in maintaining a most favorable equilibrium temperature, above all by making the cooling surfaces of the furnace only sufficiently large to keep the furnace temperature from dropping below the required level. But this way does not lead far, for, according to my investigations, one should not go below 1200° in the case of Westphalian bituminous coal, with about 30 per cent volatile matter, in the case of hard coal not under 1300°, and in the case of German brown coal not under 1100°, if the combustion is not to become too slow. Certainly a perceptible increase of heat liberation is attained hereby, but as the ignition delay can hereby rise to 0.3 second, there is very soon a limit put to liberating more heat in this manner.

The second way is *preheating* the primary air as far as possible. Not only must the dust be heated during conversion, but also the whole weight of primary air, the heating of which is primarily attained by contact with the large surface of the dust, which becomes heated under the influence of the furnace-radiation. Cold combustion-air therefore has a cooling effect on the dust, and prolongs the conversion period. Therefore, preheating of the primary air as far as possible, is an effective measure for reducing the combustion time and increasing rate of heat liberation as hereby the conversion-velocity becomes independent of the amount of heat given off to the cooling surfaces of the furnace. The temperature necessary for preheating the air is thereby to a great extent determined by the amount of volatile matter contained in the coal. As I tried to explain, the coal cannot possibly be noticeably degasified during the short conversion period. But yet degasification is surely a process, which takes place in less time than complete combustion. Besides, the combustion time of the gases which have been given off is far shorter than that of the coke-residue, so that from the moment when a perceptible development of combustible gases commences, their combustion accelerates the conversion velocity enormously. For, in the first place, these gases are ignited immediately after emerging out of the heated surface and radiate back onto it; secondly, they rise with the cold air which they heat. Therefore, in the case of low volatile coal, the less this help of gas-combustion is available, the higher the preheating of the air must be. Besides the acceleration

of conversion caused by preheated air, more heat is liberated as Figure 7 shows. For, remembering equation (3) the numerator will be increased, since preheating means an increase of the calorific value of the fuel, while, due to dissociation, the temperature will not rise proportionally. Therefore, the rate of heat liberation can be increased essentially by preheating the combustion air. Dissociation, however, always means a retardation of complete combustion, but refers to the reaction of already gaseous products and does not concern the combustion period of the solid dust particle.

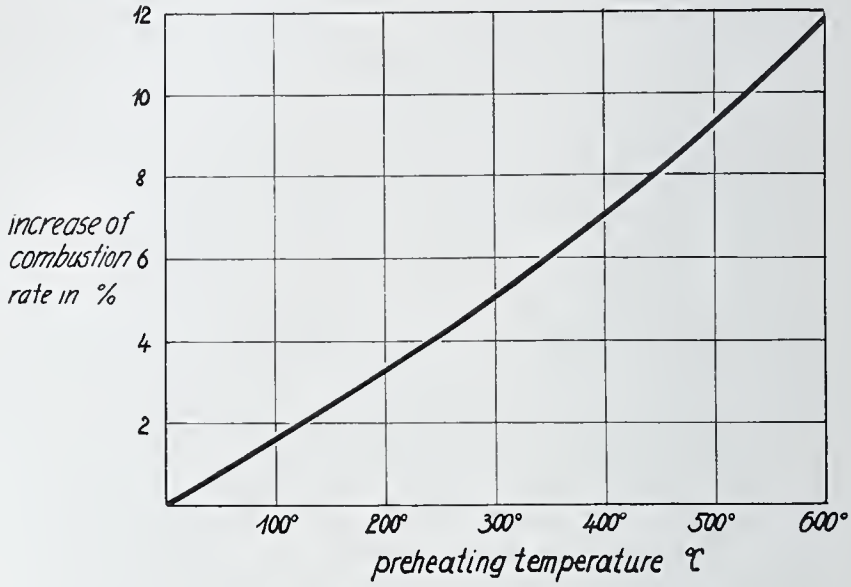

FIG. 7. RISE OF LOAD BY PREHEATING

But there is still a third way, which, however has not yet been taken in the case of powdered coal. It consists of preheating the fuel by making use of *ignition chambers*, which are known from solid injection Diesel Engines. We have seen that the greatest part of the conversion heat is swallowed up by the primary air, and that very great acceleration takes place on account of liberation and rapid combustion of the volatile matter. Therefore, if one were to preheat the dust in a very small ignition antechamber to such an extent that when it entered the combustion chamber, already sufficient combustible gases were liberated, that the first part of the conversion (heating and pyrogenic decomposition) had already taken place, one could reduce the ignition delay to a fraction of a hundredth of a

second, the more so, as the degasified residue is in a state of extremely strong adsorption- and auto-oxidation capability. In this, it is unnecessary to copy the pattern of the compressorless Diesel Engine too closely, and to only preheat the fuel in the ignition chamber, as one would encounter difficulties with the customary method of blowing the dust in. We can, in any event, let part of the air pass through the ignition chamber, and so design its length that ignition begins as soon as the fuel enters the furnace. By this method we gain useful combustion room, which hitherto was used for the conversion and is too expensive for this purpose.

The Influence of Aerodynamic Conditions (Turbulence) on Rate of Heat Liberation

Since the conversion and the combustion of coal dust constitute a reaction of two different phases, it is primarily a pure surface function. Since the reaction products possess another phase than the solid residue, they therefore very soon form a blanketing layer between the fuel and the oxygen of the air. Even the pure physical process of the first heating as far as it takes place by contact and convection, is retarded by formation of such blanketing layers. Therefore, as for all other physical and chemical processes, the velocity is dependent on the rapid destruction of the separating layer.

The reaction-velocity, according to the law of mass action, is determined by temperature and concentration. When applying the law to the combustion process, one must always keep in mind that it is a static and not a dynamic law. For it can always apply only to the condition which prevails in the reactive limit-layer during the reaction of different phases. We have already seen that the temperature in the limit-layer is quite different from the mass of gaseous reaction products. The same is true for concentration. The oxygen-concentration decreases very rapidly in the limit-layer. Fresh oxygen is conveyed to it to a very small extent by diffusion, to a much greater extent by the relative motion between solid and gaseous substances. Differences in density which become active when the dust is blown into the furnace, and also when it is in a state of suspension, as well as differences of density of the gaseous phases themselves, caused by the difference of temperature, produce constant relative motion. All these movements are comparatively slow. But the formation of blanketing layers is synonymous with a rapid

decrease of the oxygen concentration, and is the main reason for the combustion time being prolonged. Therefore, the most effective means for accelerating the reaction consists in violent destruction of the separating layers by most lively relative motion between the solids and the gases.

These relative movements in all their aero- or hydrodynamic forms are called turbulence. It is superfluous to mention their accelerating effect for all reactions. It is only to be proved why they are particularly useful in the case of dust firing. With all reactions, the substance formed in unit time is proportional to the reacting surface under otherwise equal conditions. Now the products formed in a second can be referred either to the unit of the reacting surface, or else to the reacting weight. The products formed relative to the surface unit are naturally constant and independent of the total surface size. The products formed when referred to the weight unit are, on the contrary, proportional to the total surface. If the dust is ground to the customary fineness, we multiply the surface about 1000 times. But it should not be concluded from this that the formation of products referred to the weight should be likewise multiplied by a thousand. That would only be the case if this surface were effective as reactive surface in its entirety. But that is not the case with most of the present-day burner constructions. The dust is blown into the furnace in a comparatively thick jet, so that what has previously been separated at the expense of power and money is reunited in the burner. Therefore, in order to really convert the potential surface, created by grinding, into free reactive surface, first of all there must, as far as possible, be an even mixture of dust and air; secondly the separating reaction layers, which form immediately, must be destroyed. And as in consequence of the large free surface, the size also of the reaction layers, formed in unit-time, is very considerable, the means for their destruction must also be more powerful. Uniform mixture and destruction of the separating layers are attained by turbulence, the effect of which can be the more easily attained the finer the division of the dust in the burner in the beginning. The correctness of this idea is best proved by the practical results of the dividing-burner in dust-locomotives.

The relations in dust-firing are quite different from grate-firing inasmuch as fuel and air enter the combustion chamber together, and from the beginning only possess a slight relative velocity. In the case of grate-firing, on the contrary, the fuel is stationary, and

the separating layer which is formed is immediately again removed by the air which sweeps past. But in the case of dust-firing, the relative velocity is smaller the finer the dust is ground. It is a well-known fact that from a certain limit onwards separation of the dust from the gases does not take place, and that therefore the necessity of turbulence is the more pressing the greater the fineness of the dust.

It is a pity that there are no particulars on hand referring to experiments regarding the numerical influence of turbulence on the combustion time of the dust. Mathematical calculations also meet with the greatest difficulties. As yet we have no approximately clear conception regarding the currents in the furnace. If we may assume that the currents during combustion are decidedly turbulent, we must still be aware that this turbulence does not suffice to attain the quickness of combustion which is necessary for high combustion rates so that we must introduce artificial turbulence with all means at our disposal. Here also mention may be made of the solid injection Diesel Engines, with which the influence of turbulence was far better studied, and taught lessons which were embodied in the design with such good results.

From the whole of these investigations the fact stands out clearly: Conversion and combustion are very complicated processes, composed of all kinds of reactions, the course of which is determined by the influences of fineness, temperature and turbulence, as already depicted. It is therefore quite impossible to pick out one single point of this very unstable process as the ignition point, and to call it a property of the fuel. It may be possible to determine physical ignition points in the laboratory under uniform conditions and to compare them with one another, but even then we must realize that it does not depend on the fuel alone, but on a number of influences outside of the fuel. For that reason, no comparable ignition points exist at all in technical furnaces. The ignition point is rather only the resonance of the fuel on the events in its surroundings.

MAXIMUM POSSIBLE RATE OF HEAT LIBERATION

The result of these investigations is that with fine grinding, suitable temperature, preheating and turbulence, very short combustion time can be obtained. But with that statement the problem is not yet solved, for we meet with all kinds of obstructions and limitations when pursuing these measures. Any desired heat liberation can be obtained above a certain dust-fineness, and theoretically

and technically there is no limit to fine grinding. But there exists limits of an economical nature. For grinding costs increase very rapidly to such a degree that the saving due to increased evaporation rates of the boiler plant, is swallowed up. Even today, the grinding plant is a heavy burden for the economy of powdered coal firing, so that engineers endeavor to get along with the coarsest possible fineness of grinding. It may become very different if coal dust is used

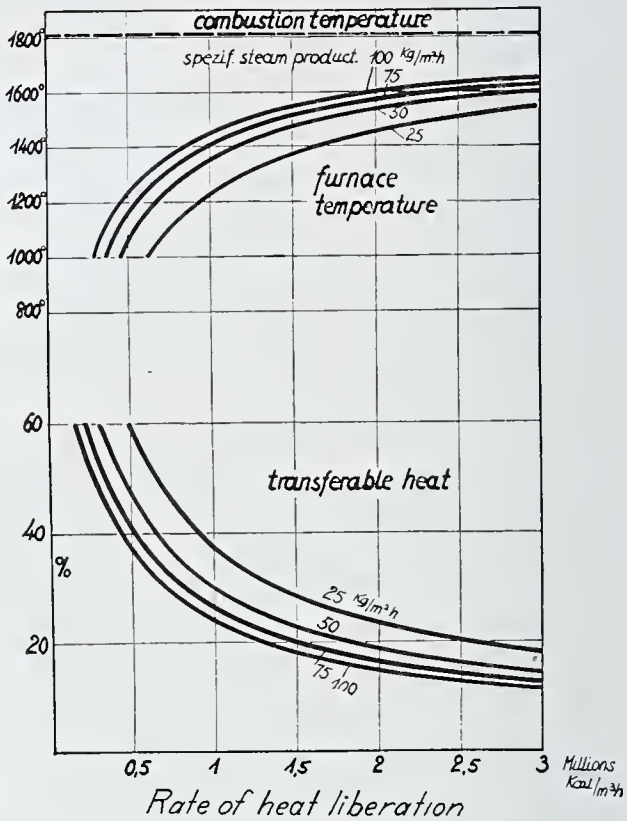

FIG. 8. TRANSFERABLE HEAT IN FURNACE (1000-M² BOILER)

for internal combustion purposes. Its use in the Diesel Engine is, apart from the ashes, nothing more than a problem of highest conversion and combustion velocity, therefore, from a thermal point of view, solely a question of heat liberation. But in the case of an engine, coal dust competes with expensive oil, so that there is more latitude for considerable increase of fineness in grinding.

The whole of the research concerned the problem of developing

as high a number of calories as possible in the furnace, but the problem of carrying this heat away in a useful manner, is just as important. It turned out that lowering the average gas-temperature was a necessary measure for increasing the combustion rate. Therefore, the question is to be raised how fast heat can be transferred to the cooling surfaces of the furnace, and what lowering of temperature is obtained thereby. In Figure 8, for the combustion of a bituminous coal of 7000 calories with 25 per cent excess air, it was assumed that 5 faces of the cubic furnace of a 1000 square meter boiler consist of heat-absorbing cooling-surfaces. The coefficient of heat transfer was assumed to have the high value of 200,000 calories per square meter per hour the highest value, hitherto measured on a coal dust furnace. It was calculated for different steaming rates from 25 to 100 kilograms per square meter per hour. The lower part of the illustration shows the amount of developed heat which the cooling-surfaces can absorb. The upper part gives the actual furnace temperatures, which establish themselves in consequence of this loss of heat. With heat liberation rate of one million and 50 kilogram steaming rate the temperature is already 1360°, and in the case of higher combustion rates, heat transfer causes only trivial lowering of temperature. But with that the very effective measure of lowering the temperature drops out as long as one does not arrange the cooling surfaces in a very different manner. From this one recognizes the necessity of increasing the heat transfer to the cooling and heating surfaces. This velocity problem no longer concerns the combustion time but the cooling-period and is just as important. Quick combustion is advantageous only if it is bound up with rapid heat-abstraction.

As grinding-fineness very soon reaches its economic limits, and lowering of temperature can only be achieved with low rates of heat liberation, turbulence has to play the principal part. The products of combustion which are formed, must be carried away just the same as the developed heat. These limits of heat liberation are determined by the permissible or attainable gas-velocity. The theoretical limit of the gas-flow is reached at the velocity of sound, and it may be here only mentioned that this velocity corresponds to a heat liberation of about 100 million calories per cubic meter per hour (11 million B.t.u. /cu. ft $\times$ h). Even if here the theoretical limits lie far beyond practical endeavors, still attention must be called to the fact that combustion time, maximum heat liberation, furnace-size, and gas-

velocity are bound together in conformity to natural thermodynamic law, which should not be lost sight of during design.

Investigation of the thermal foundations thus shows dust-firing to be decidedly a velocity problem. Theoretically, the maximum heat liberation of the furnace is inversely proportional to the combustion time and the latter itself is a complicated function of dust-fineness, temperature and the aerodynamic relations of the furnace, practically it depends on the velocity of heat transmission to the boiler tubes.

I have endeavored, at least in a qualitative manner, to work out these influences, and a series of practical conclusions can be drawn from them. Nevertheless, I am aware that I have touched upon more problems than I have solved. But dust-firing, as well as the thermodynamics of technical combustion, are still in their infancy, and I therefore believe that correct recognition of its problems may be looked upon as progress.

BURNING OF BITUMINOUS COAL IN PULVERIZED FORM

By Henry Kreisinger

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One of the reasons for the steady progress in the burning of pulverized bituminous coal is the fact that the rate of combustion and the air supply can be as easily controlled as in burning gaseous fuel or oil. This is the first impression one gets when visiting an installation of powdered coal. The methods of regulation and the appearance of the flame of pulverized coal are very similar to that of burning gas or fuel oil. However, the physical and chemical properties of powdered coal are different from those of gas and fuel oil and the actual process of combustion is much more complicated. As a result the rates of combustion that can be maintained in practice with powdered coal are lower than those in common practice with gaseous fuel or fuel oil.

Burning of Bituminous Coal in Pulverized Form. Pulverized coal consists of particles varying in size from about $\frac{1}{100}$ of an inch to $\frac{1}{1000}$ of an inch, the average size of about $\frac{1}{400}$ of an inch. Even the smallest particles consist of a very large number of molecules which cling firmly together. The size of an oxygen molecule is about $\frac{1}{100,000,000}$ of an inch. The average size of coal particles is then about 250,000 times greater than the oxygen molecules. This comparison of sizes gives an idea of the very large number of molecules an average size coal particle contains and of the very large number of oxygen molecules required for its complete combustion.

Only a small part of the coal particles can be set free as individual molecules during the process of distillation and burned in a somewhat similar way as fuel oil. The remainder of the combustible stays in the particle as fixed carbon and must be burned by bringing oxygen in contact with the surface of the particle.

The molecules of fixed carbon are also very complex; that is, each molecule consists of many atoms so that a large number of oxygen molecules are required to burn a molecule of fixed carbon. Nothing definite is known about the molecular structure of coke or soot but

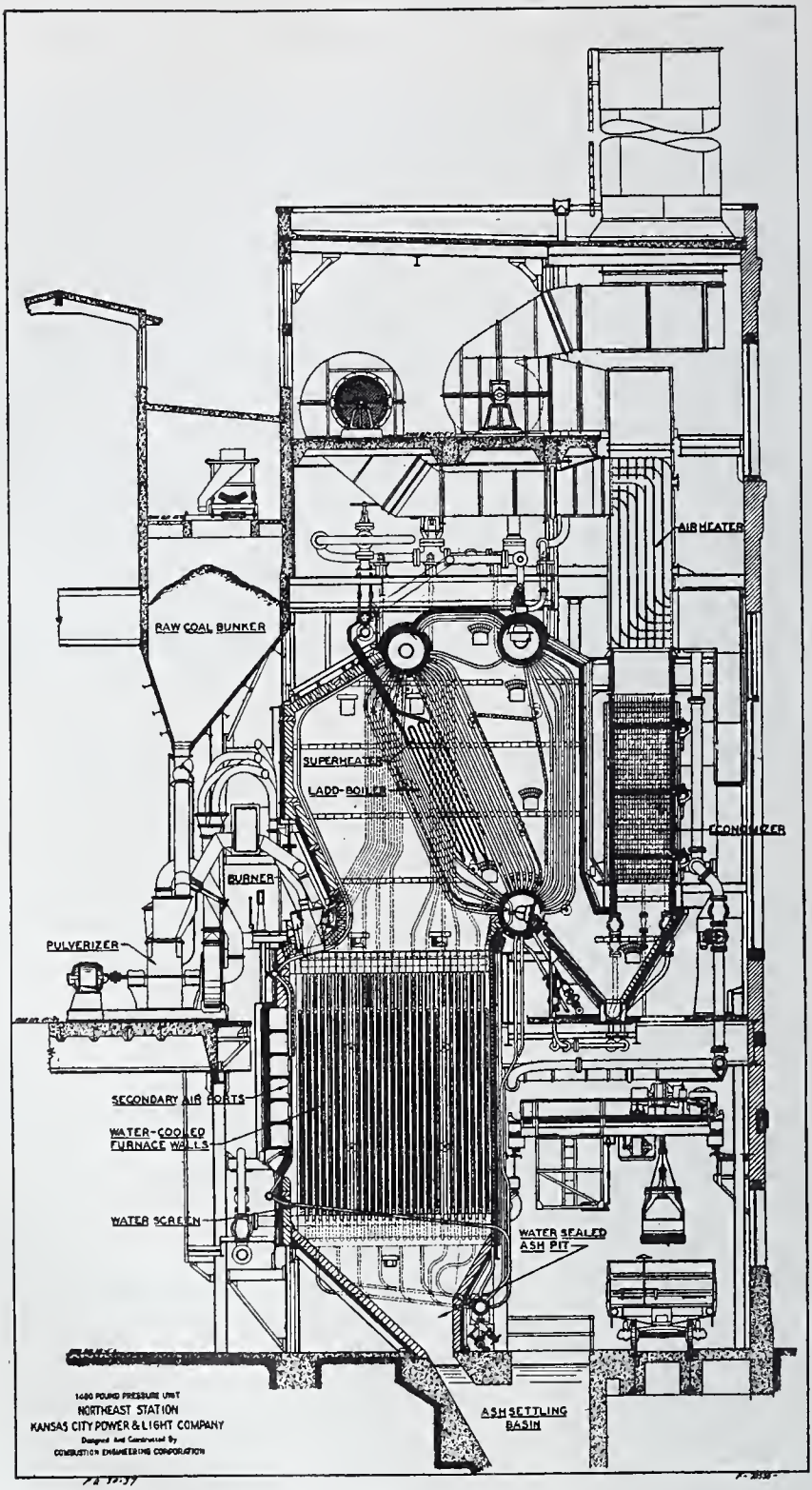

Fig. 1. Vertically Fired Water-cooled Furnace of 1,400 Pounds Pressure Boiler of Kansas City Power and Light Company

it is thought that each molecule consists at least of 12 atoms in which case 12 oxygen molecules would be required to burn 1 molecule of fixed carbon. Therefore, a very large number of oxygen molecules must be brought into contact with the surface of the particles of coke before they can be completely burned. This is the reason that pulverized coal requires more time and a larger furnace for complete combustion than either gaseous or liquid fuels.

It is important to bear in mind that bituminous coal is not a mixture of fixed carbon and volatile matter, but a mixture of heavy hydrocarbons, which are solid at ordinary temperatures. When these heavy hydrocarbons are heated they break into coke and lighter hydrocarbons which are distilled from the coal in the form of gases and tar vapors, leaving the fixed carbon as a residue. If the distilled hydrocarbon vapors are quickly mixed with oxygen sufficient for their complete combustion, they may burn directly without further breaking. If, however, the oxygen supply is insufficient they keep on breaking into carbon and more stable hydrocarbons with the ultimate products of soot, hydrogen and carbon monoxide.

All hydrocarbons are unstable at the furnace temperature. Even methane, which is probably the most stable hydrocarbon breaks into soot and hydrogen. Soot has a complex molecular structure like coke, and is therefore slow burning.

The preceding discussion of the physical subdivision of powdered coal and its chemical composition and behavior when heated shows that only a comparatively small part of the coal can be brought into molecular subdivision, with the individual molecules moving freely in the space as in the case of gaseous fuel and to a large extent with fuel oil. Most of the combustible remains in a comparatively large mass as fixed carbon after the process of distillation has been completed, and must be burned by bringing oxygen in contact with its surface. The volatile matter which has been distilled from the coal burns in a somewhat similar manner as the fuel oil although probably not as quickly because the hydrocarbons coming from the coal are heavy and there is a greater tendency on their part to break into soot and lighter hydrocarbons.

Behavior of Coal When Heated. Coking coals soften and become sticky when heated to a temperature at which a large part of the volatile matter is distilled. While in this state two or more coal particles may stick together and form a larger piece requiring longer time to burn. This is indicated by the fact that when burning these

coals in pulverized form the flue dust frequently contains larger pieces of coke than the original coal particles.

Free burning coals when heated do not become sticky enough for the particles of coal to stick together and form larger pieces. In addition to this, these coals usually have a higher volatile content so that a smaller part is left as fixed carbon after the process of distillation is completed. The particles of coke are smaller and less time is required for their complete combustion than in the case of the coking coals.

Sub-bituminous coals and lignites disintegrate when heated. When burned in pulverized form the particles are very likely broken up into much smaller particles, and therefore the fixed carbon consists of very small particles which require a short time for their complete combustion.

Feeding Pulverized Coal and Air to Furnace. Pulverized coal is supplied to the furnace in a mixture with primary air consisting of about 30 per cent of the total air needed for combustion. The air is used as a carrier for the coal and supplies the oxygen necessary for ignition. The remainder of the air, called the secondary air, is either supplied through special ports in the front wall of the furnace, or through the burner around the nozzle carrying the primary air and the coal.

Ignition of Pulverized Coal. The coal particles upon their entry into the furnace are heated at first slowly by radiation from the flame in the adjacent part of the furnace. This heating starts the distillation of the volatile matter and when this volatile matter and the primary air have reached the temperature of 900° to 1,200°F. the volatile matter bursts into flame. This flame surrounds the coal particles and heats them rapidly causing a rapid distillation of the remaining volatile matter and making more gaseous products available for combustion.

Combustion of Volatile Matter. The distilled volatile matter diffuses into the surrounding air and burns as fast as it meets with oxygen. The process of diffusion is rather slow and if the volatile matter were left to this means of meeting oxygen, the process of combustion would be slow. A large part of the heavy hydrocarbons of the distilled volatile matter would break down into soot and the more stable gases of simple molecular structure. These gases would burn first because they require less oxygen for their combustion, leaving the soot in suspension. The resulting flame would be sluggish and luminous due to the presence of the incandescent parti-

cles of soot. The flame would also be long and inclined to produce black smoke.

If on the other hand the mixture of coal and air is strongly agitated after ignition has taken place the hydrocarbons distilled from the coal are brought quickly in contact with oxygen and a large part of them burn directly without first breaking into soot and stable gases. Because of the comparative absence of soot the resulting flame is clear and short.

Combustion of Fixed Carbon. It must be remembered however that the visible flame is the result of burning volatile matter. Beyond the tips of this visible flame the fixed carbon is burned and space must be provided for its complete combustion. The amount of combustion space and the time required depends on the amount of combustible that has been left to burn as fixed carbon, on the size of the particles, on the concentration of oxygen available for combustion, and on the intensity of mixing. With coking coals high in fixed carbon the particles of carbon are large and a very large number of oxygen molecules must be brought in contact with them before they are completely burned. The furnace must be either large or the mixing intensive if they are to be burned completely. With the free-burning, low-fixed carbon coals the particles of coke to be burned as fixed carbon are smaller and a smaller number of oxygen molecules are required for their complete combustion. Therefore, a smaller combustion space is needed beyond the tips of the visible flame for the complete combustion of these coke particles.

The sub-bituminous coals and lignites are, as a rule, less dense than the high-grade bituminous coals. That is, the same size particle contains less combustible. The particles disintegrate in the furnace and a large part of these small particles is distilled and burned as volatile matter, leaving only a very small amount of combustible in very small particles to be burned as fixed carbon. These very small particles easily find the small amount of oxygen needed for their combustion and, therefore, the combustion space needed for their complete combustion needs to be relatively small. When burning these fuels in powdered form the flue dust contains very little unburned carbon even when the tip of the flame extends beyond the furnace and into the boiler. While with the coking-coal the combustible in the flue dust usually amounts to 25 per cent and with the free-burning bituminous coal 5 to 10 per cent, with the sub-bituminous coals and lignites the combustible in the flue dust may not exceed 1 per cent.

Mixing Causes Rapid Combustion. At ordinary furnace temperatures the combustible burns as fast as oxygen is brought in contact with it. Mixing greatly increases the rate of combustion. Mixing may be defined as the process of changing relative position. In case of burning coals, mixing is the process of changing the relative position of the combustible and the oxygen needed for combustion. The combustible is moved from one position where all the oxygen has been used into another position where there is still oxygen. In other words, mixing is relative motion of the combustible with respect to the products of combustion and oxygen. The combustible still to be burned is moved out of an envelope of products of combustion into an atmosphere containing free oxygen. The greater this relative motion, the more rapid the combustion.

High Rate of Combustion on Grate Due to High Relative Velocity. When coal is burned on a grate or stoker, it is easy to obtain high relative motion. The coal stays on the grate while the air is passed over its surface at a high velocity. Thus, coal can be burned in a 6-inch fuel bed of uniform density at the rate of 25 to 100 pounds per square foot of grate per hour by passing air through the fuel bed at varying rates. During the passage of the air through the fuel bed all the oxygen is combined with the combustible. The gases rising from the fuel bed contain only CO_2, nitrogen and 15 to 30 per cent of combustible gas. This indicates that coal can be burned or gasified as fast as oxygen is brought in contact with its surface. With the average American bituminous coal 7 pounds of air will burn or gasify 1 pound of coal. This weight of air per pound of coal burned or gasified remains nearly constant through a wide range of rate of gasification, provided that the fuel bed is of uniform density and free from holes or air channels. When the rate of combustion is 25 pounds of coal per square foot of grate per hour the average velocity of the flow of air through the fuel bed is about 10 feet per second; when the rate of combustion is 100 pounds this average velocity is about 40 feet per second. If the fuel bed is assumed to be 6 inches thick, the time the air is in contact with the coal is $\frac{1}{20}$ and $\frac{1}{80}$ of a second in the two cases. With a 6-inch fuel bed the coal occupies 0.5 cubic foot and the rates of combustion or gasification in the two cases are 50 and 200 pounds of coal per cubic foot of combustion space per hour. This is a very high rate compared to burning of pulverized coal where the usual rate is 1 to 2 pounds of coal per cubic foot of combustion space per hour. It is true that the coal is not

burned completely in the fuel bed. The coal not burned is, however, changed into a gaseous state with the individual molecules moving freely in space in which state they can easily find the oxygen required for their complete combustion, providing that this free oxygen is supplied over the fuel bed. This high rate of gasification of coal in the fuel bed is due entirely to the high relative velocity of air over its surfaces.

Relative Velocity Is Low When Burning Pulverized Coal. When burning pulverized coal the relative velocity between the coal particles and air is low. It is probably measured in inches and seldom exceeds 1 foot per second. The particles are light and tend to move with nearly the same velocity as the air.

If high relative velocities between the coal particles and the surrounding air are to be produced energy must be provided. The mixture of primary air, coal and secondary air is blown into the furnace with velocities between 60 and 150 feet per second. The primary and secondary air must move in different directions. Parallel streams must be avoided if relative velocity between the air and coal particles is to be produced. In other words the streams must produce turbulence.

In cases where the secondary and the primary air are supplied in different directions through the burner, the mixing is very intense near the burner and the relative velocity between the coal particles and the air is high. Therefore contact between oxygen and coal particles or the volatile matter distilled from them occur rapidly and combustion takes place at high rates. The volatile matter is distilled and burned quickly and a short visible flame results.

After the kinetic energy of the mixture has spent itself in friction produced by the relative velocity, the mixture of the remaining coke particles, the products of combustion and whatever oxygen that is left, tend to move in parallel stream lines towards the gas outlet from the furnace due to pressure difference produced by the draft. Most of the oxygen has been used in combustion and under these conditions the frequency of oxygen coming in contact with the surface of the coke particles rapidly decreases and the combustion is slow. With high fixed carbon coals this results in high percentage of combustible in the flue dust, in spite of the short visible flame near the burner. It is desirable when high-fixed carbon coal is burned in pulverized form that the burners and air admission are so arranged and the furnace so shaped that the turbulence continues throughout

the furnace. That is, not all of the energy supplied for mixing should be spent near the burner. Part of it should be reserved or additional energy supplied for the mixing beyond the visible flame where the fixed carbon must be burned.

Methods of Firing. There are three general methods of admitting coal into pulverized fuel furnaces, viz.: vertical, horizontal and tangential.

The first two methods and the types of burners used are well known to the engineering profession.

The tangential method is comparatively recent and, although there are some successful installations, further improvements may be expected.

In the tangential method of firing one or more burners are placed in each corner of the furnace, and the streams of the mixture of coal and air are directed towards the center tangent to a small circle. Primary air and coal is supplied through the burner nozzle. The secondary air is supplied under pressure around the nozzle and in the same general direction as the primary air. Usually only a small amount of mixing occurs near the burners, but a very intensive mixing is produced where the streams from the four corners meet near the center of the furnace. The mixing is produced by the impingement of the streams against each other. Due to the fact that these streams are tangent to a small circle a rotative motion is produced, which persists through larger part of the furnace. The rotation of the mixture and the eddies in the corners of the furnace caused by this rotation produce relative velocity between the coal particles and the gases. The rotative motion also equalizes the distribution of the coal throughout the furnace. There is, however, a tendency for the coarser coal particles to concentrate along the walls of the furnace, due to the centrifugal force produced by the rotation. The coarse particles of coal may strike the wall and drop to the bottom of the furnace. In case the burners are located at the top of the furnace and the general motion of the mixture is downwards, this segregation of the coarse coal particles along the furnace walls and their dropping to the bottom of the furnace is a weak point of this method of firing. The coarse particles may fall to the bottom of the furnace faster than they can be burned after they are deposited. The eddies in the corners of the furnace are particularly favorable to the dropping of the coarse coal particles.

If, however, the burners are placed near the bottom of the furnace

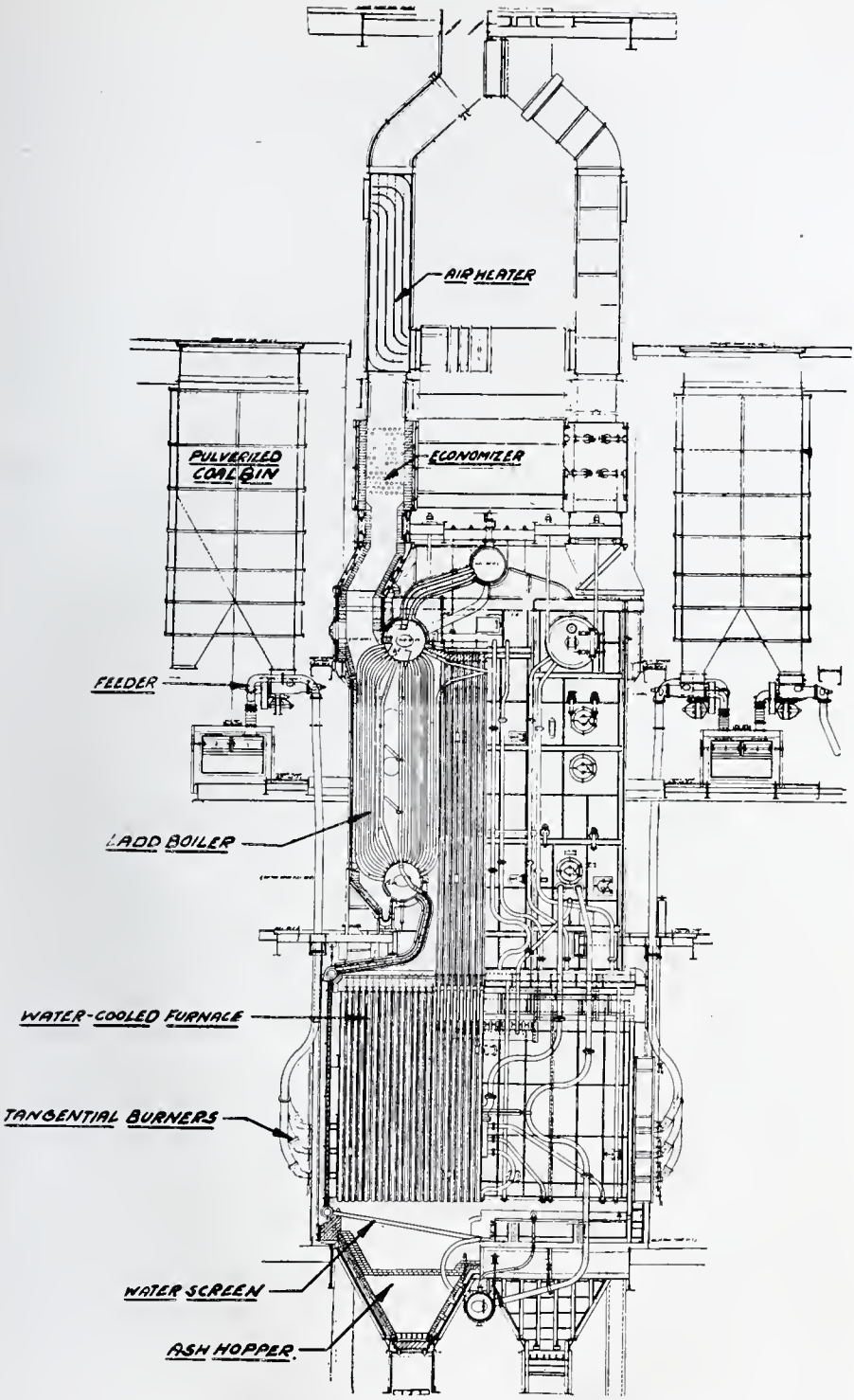

Fig. 2. Water-cooled Furnace with Tangential Firing

The illustration shows No. 4 unit of the Kips Bay Station of the New York Steam Corporation. Capacity of unit 500,000 pounds of steam per hour.

and the mixture moves in a general upward direction, any coarse particles that may be falling move against the rising gases with a comparatively high relative velocity which brings oxygen in contact with their surfaces, and causes them to burn rapidly. Most of the particles are burned before they fall very far. The few that may continue to fall eventually reach the streams of mixtures from the burners and are again projected by them towards the center and are given a second trip through the furnace. Therefore, with the tangential firing the burners should be placed near the bottom of the furnace, and the mixture should move in a helix in a general upward direction.

The tangential firing of this type is far more effective in producing and maintaining intensive mixing in the furnace and therefore makes possible higher rates of combustion than any other method of firing. It is especially well adapted to the very large steam generating units with water cooled furnaces that are to be operated at high rates of steam output. One of such units is shown in Figure 2. It is the No. 4 unit of the Kips Bay Station of the New York Steam Corporation. The two furnace arches of this unit tend to stop unburned coal particles from being carried into the boiler.

Shape of the Furnace. The shape of a furnace is an important factor in furnace design. Although it is largely determined by the shape and type of the boiler, the designer still has considerable margin in determining the shape. In general for vertical and horizontal firing a wide and short furnace is better than a long and narrow one. The length of the furnace in this case refers to the distance between the front and rear wall, and the width is the distance between the side walls. The wide furnace permits more burners and thereby makes possible a better distribution of coal and air throughout the furnace. In a narrow furnace the number of burners must either be reduced or the burners crowded closely together. Thus the mixture of coal and air has not sufficient room to spread out in the furnace and use the kinetic energy for mixing. The flames are crowded between the side walls and there is a greater tendency for the furnace gases to move in stratified streams. In narrow refractory furnaces the side walls are subject to excessive erosion by the impingement of flame.

In the case of vertical firing the short and wide furnace has a sharper turn of the flame near the bottom of the furnace. This sharper turn produces more intensive mixing at the turning point,

and the flame more completely fills the furnace. With narrow and long furnace the turn of the flame is of greater radius resulting in less agitation at the turn and usually leaving a space free from flame in the central part of the furnace in which very little combustion takes place. Most of the gases enter the boiler along the rear wall and a comparatively small amount flows into the front part of the boiler.

There is a tendency to make long, narrow and high boilers because this design makes it possible to put in large amount of heating surface for the least cost. This is particularly true of the straight tube horizontal water tube boiler. It is hard to design a good furnace for such boilers, and as a rule the boilers can not be operated satisfactorily at as high ratings as wider and lower boilers. Thus for example, a boiler 20 tubes high and 20 tubes wide will have the same heating surface as a boiler 10 tubes high and 40 tubes wide, the length of the tubes being the same in both boilers. On the 40 tubes wide boiler it will be possible to put in a furnace twice as wide and the cross section of the gas passage into the first pass will be twice as great as on the boiler 20 tubes wide. Thus, with the same rate of combustion and same velocity of gases entering the first pass the wide boiler can be operated at nearly twice the rating as the narrow and high boiler. If attempts are made to operate the narrow boiler at the same rating as the wide boiler, the boiler tubes in the first pass may slag over.

The furnace should be as deep as practicable. The deeper the furnace the longer the gas travel through the furnace and the more complete is the combustion of the fixed carbon, the conditions of mixing remaining the same. For small units the depth of the furnace should be at least 15 feet between the bottom of the furnace and the boiler tubes. With larger units this height should be 25 to 30 feet or even greater. With some of the bent tube large size boilers the distance between the bottom of the furnace and the top of the combustion space is as much as 50 feet.

With the tangential firing the ideal shape of the furnace would be one having a nearly square cross section, especially if the furnace is of comparatively small size. The square section is favorable to the helical path of the gases through the furnace. On larger size furnaces this is not so important, the section can be a short rectangle, with the longer side perhaps as much as 50 per cent longer than the shorter side.

The Size of the Furnace. The size of the furnace depends entirely

on the amount of coal to be burned, the character of the coal, and the material used in the construction of the furnace. The usual rate of combustion is 1 to 2 pounds of coal per cubic foot of combustion space per hour. This corresponds to a rate of heat liberation of about 12,500 to 25,000 B.t.u. per cubic foot per hour. If the furnace is built of refractories the rate of heat liberation for continuous service should not exceed 18,000 B.t.u. per cubic foot per hour, and should be lower if the ash of the coal is very fusible. If this rate of combustion is exceeded the ash of the coal will fuse and erode the refractories resulting in very high maintenance of the furnace. It would be also very difficult to remove the ash deposited on the bottom of the furnace, because the ash would fuse making it necessary to shut down the unit for its removal. In water cooled furnaces there is no danger of erosion of the walls and the ash collected at the bottom is usually prevented from fusing by the use of a water screen. Therefore, high rates of combustion can be used. It is entirely feasible to maintain a furnace of that type in continuous service with a rate of heat liberation of 30,000 B.t.u. per cubic foot of combustion space per hour. This rate of heat liberation can be exceeded for peak load periods. The limit to the rate of combustion is usually the slagging of the boiler tubes and clogging of the gas passages.

Furnace Walls. Solid refractory, air cooled refractory, and water cooled furnace walls have been used as well as combinations of all three.

The solid refractory wall usually wastes away rapidly unless the furnace is large and the rate of heat liberation low.

With the hollow air cooled walls the rate of heat liberation can be increased about 20 per cent but the air cooling does not prevent erosion where the flame comes into contact with the brickwork.

The completely water cooled furnace lining has been developed recently and entirely eliminates erosion and makes very high rates of heat liberation possible without a corresponding high maintenance cost. The greater capacity and lower operating cost offset the higher first cost of this type of furnace.

Ash Disposal. About 20 per cent of the ash in the coal drops to the bottom of the furnace and is removed in various ways depending on the size of the unit, local conditions, and the judgment of the designer.

Recently a few installations have been made in which the ash collected at the bottom of the furnace is removed in liquid form.

The molten ash is run into a spray of water by which it is quickly chilled and disintegrated into small pieces which are sluiced into a settling basin. The liquid slag is tapped off once or twice a day and each tapping lasts about one to one and a half hours.

A small part of the ash not deposited on the furnace bottom settles in the soot hoppers and ducts. Most of it however stays in suspension in the products of combustion, and is carried out through the stack unless it is washed out or precipitated by special devices.

Electrostatic precipitation is very efficient in removing the fly ash from gases if the velocity of gases through the precipitator does not exceed 10 feet per second. Two large Central Stations in the United States are using such precipitators very successfully.

A satisfactory method of washing the ash from the flue gases has not yet been developed.

THE MODERN STOKER AND ITS COMPARISON WITH PULVERIZED COAL FIRING

By James W. Armour

Vice President and Engineering Manager, Riley Stoker Company, Worcester, Massachusetts

In outlining the present status of stokers and pulverized coal and their comparison in handling bituminous coals, it is advisable to study the conditions surrounding their development to the point they have now attained. Forty years ago the first underfeed stoker was made. (Fig. 1.) The inventor had in mind only the burning of wet wood and to accomplish this purpose he pushed logs of wood up under the fire so they might be dried out before entering the zone of combustion. Later the same principle was used to force bituminous coal into the furnace so that the volatiles were distilled and passed through a hot zone where they were burned before reaching the cold surface of the boiler. It is a long cry from this crude device to the present high duty, highly efficient, multiple retort underfeed stoker (Fig. 2) but the principle, as applied to underfeed stokers, remains the same, in fact even now stokers are being made that bear a distinct resemblance to the original model.

Pulverized coal firing, as related to steam plants, is of comparatively recent development. It is only within the past five years that pulverized coal firing has been given general consideration as a means for introducing coal into the furnace of a steam generator. Therefore stokers have passed through a long period of development, whereas pulverized coal is still in the early stages.

It is true with any device, which has wide use, that development proceeds at a rapid rate when the idea is new, for the interest is keen and concentration on the problem brings out new phases, new combinations and new solutions of the obstacles encountered. Then there usually follows a period of lagging interest when development does not proceed as rapidly and changes are made only when necessity demands, until such time as circumstances or competition from other sources either replace the device or arouse new interest in it.

The greatest factor in recent stoker development can be traced almost entirely to competition of pulverized coal firing. Activity in design and application of pulverized coal to steam generating plants

has been extremely strenuous in the last few years with the result that its performances have received close attention and development has proceeded at a rapid pace. The use of pulverized coal brought out the limitations imposed by conventional methods of building boiler furnaces, with the resulting concentration on the problem of overcoming these limitations and evolving solutions which have permitted widening the scope of pulverized coal firing with economies exceeding anything ever believed possible with stoker fired furnaces.

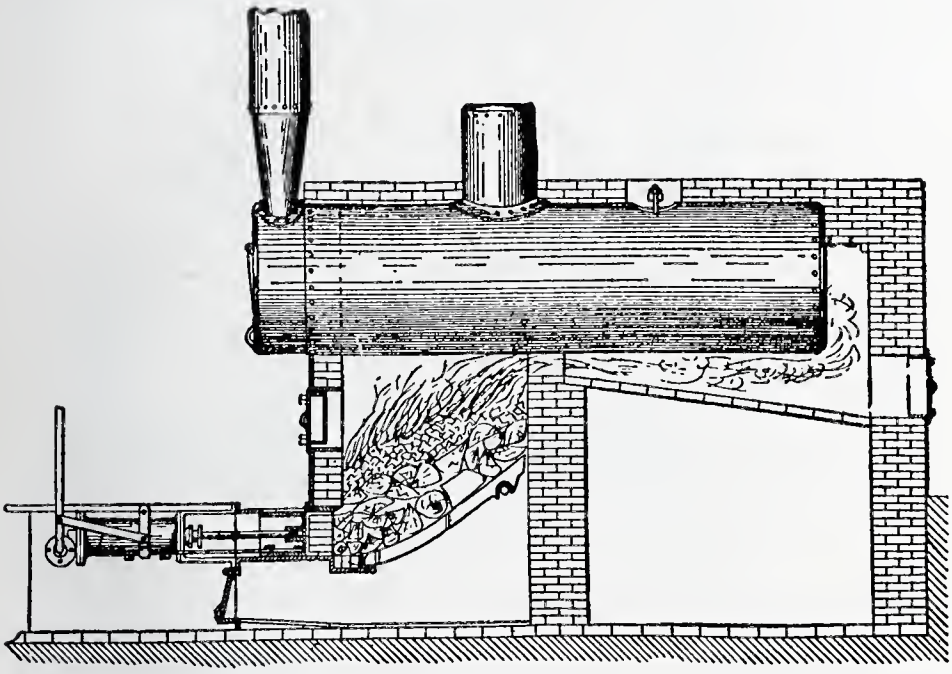

FIG. 1

The natural sequence was to apply to stokers those devices which have contributed to the success of pulverized coal firing and this has been done so successfully that there is renewed interest in stoker design and application.

There are, to my mind, three outstanding factors in the design and application of stokers which have contributed in the very recent past and will contribute in the very near future to the advancement of the science of burning coal on a fixed grate.

First: Use of preheated air.

Second: Proper application or admission of air to the fuel bed.

Third: Substitution or supplementing of refractory lined furnaces with water cooled or air cooled walls.

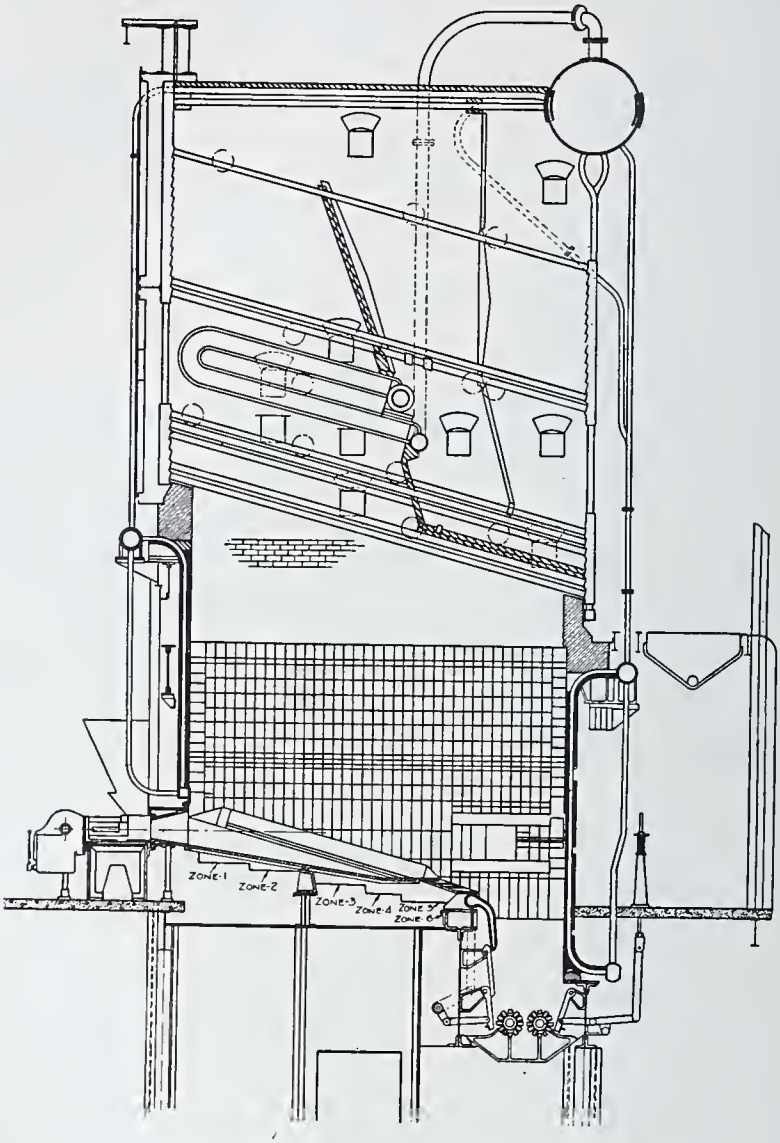

FIG. 2

The general use of preheated air with stokers is comparatively recent. It is only in the last five years that the advantages of preheated air have been recognized and only in the last two years that use of preheaters has reached the stage where they are considered

and generally included as part of the modern boiler room equipment. Preheated air is now being used not only in large central stations, but also in small industrial plants which do not possess the highly trained personnel of the central stations and this means that operation with it must be free from petty troubles or from problems which are solved only by a highly trained engineer.

At the Hillsboro Mills, Wilton, N.H. two H.R.T. boilers, of 250 h.p. each, are equipped with underfeed stokers. Preheated air is used at temperatures of 490° to 520°F. (Fig. 3.) This is a typical case of a small plant where highly trained personnel are not in con-

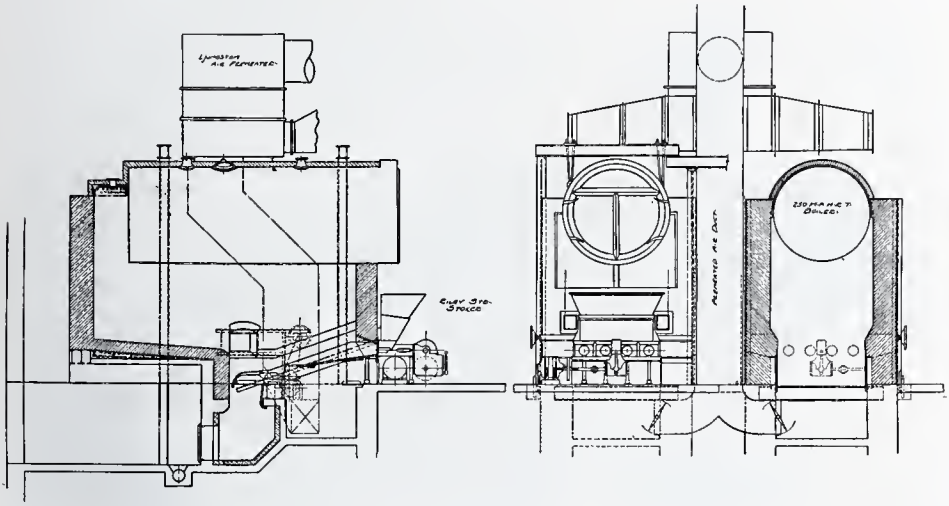

FIG. 3

tinuous contact with the power house, yet they are operating successfully with this high degree of preheat.

To permit the use of preheated air, stokers must be designed to take care of expansion due to higher temperatures and the tuyere openings must be properly proportioned so that the greater volume of air is correctly handled. These problems are being successfully met so that preheated air can no longer be considered an experiment when applied to stokers.

The effort to properly admit air to the fuel bed is resulting in one of the greatest forward steps in the development of underfeed stokers. Zoning of air for combustion, so that complete control is provided throughout the fuel bed, is not new, but its value as applied to underfeed stokers has probably not been fully realized until quite

recently. Chain grate stokers have been zoned almost since their conception. In fact, zoning on the chain grate is practically a necessity on account of the thin fuel bed and its changing characteristics as it progresses from the front to the rear of the furnace. Moreover the zoning principle has been used in multiple retort underfeed stokers for a long time, but consisted mainly in providing separate air controls to the underfeed and overfeed sections. (Fig. 4.) This separation of air pressures was sufficient for very good results for, up to a few years ago, the underfeed portion of the stoker was not very long and separation of air control to provide for the different types

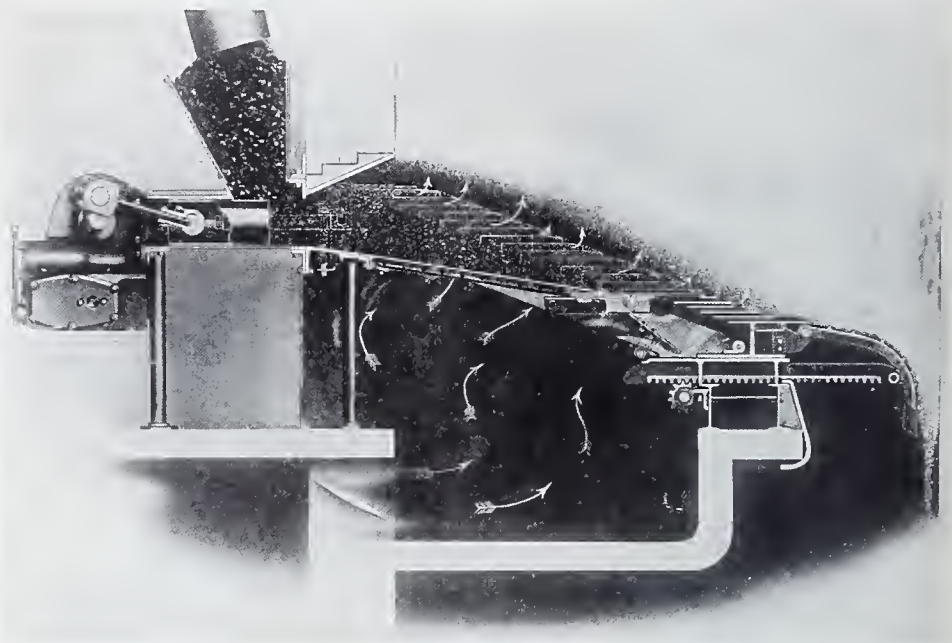

FIG. 4

of burning which takes place on underfeed and overfeed sections was sufficient to meet most requirements.

Then came the demand for greater capacities. Boiler manufacturers increased the size of boilers without a proportional increase to the width. This forced the stoker manufacturers into longer stokers (Fig. 5) until stokers are now built twice as long as the limit established six or seven years ago. The result is a long underfeed section with a greatly varying depth of fuel bed and the logical step was to provide control of air to this fuel bed in proportion to its quantity and condition.

With regard to furnace design and to the effect on stoker development, the stoker user has followed the lead set by pulverized coal. Water cooling of furnaces in connection with stokers is not by any means new, but the extensive use of water cooled walls is comparatively recent. In the case of pulverized coal, as increased ratings of boilers were demanded, limitations of furnace design were soon reached and refractories were taxed beyond their ability to withstand

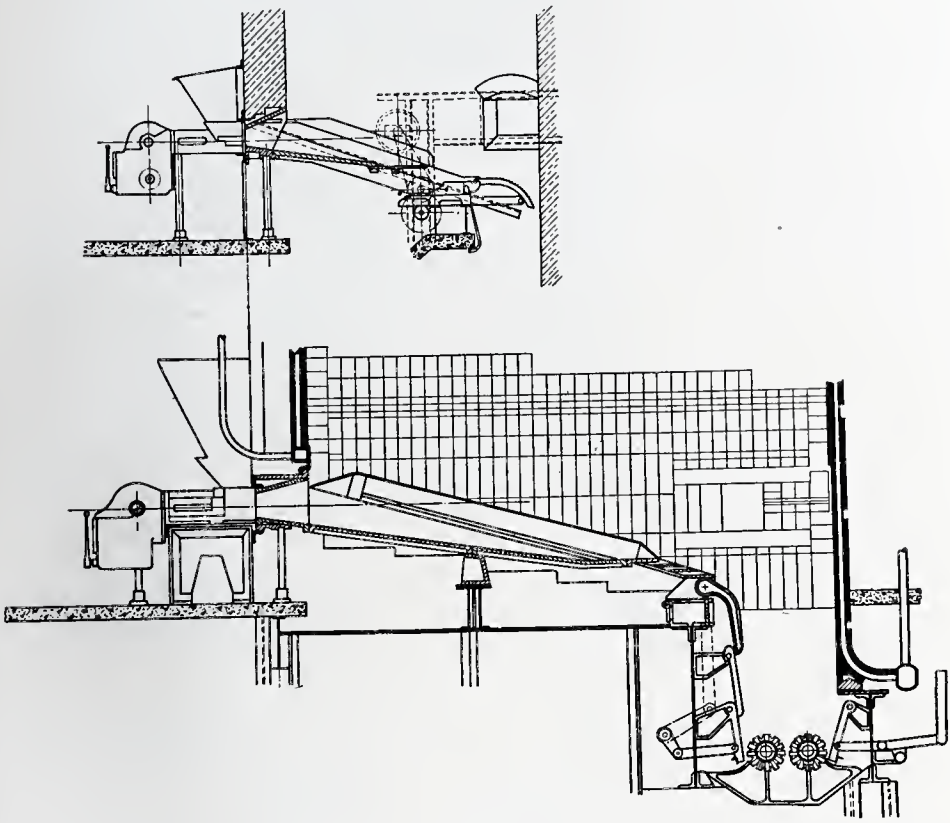

FIG. 5

the loads imposed by high walls and high temperatures. Water cooled walls proved to be the answer and permitted increased ratings over that obtainable with refractory walls. Coal of low fusing ash can be used, where before it was out of the question. All of the reasons for use of water cooled walls in connection with pulverized coal installations became applicable to the same problems confronting the designer of stoker fired furnaces. The result is that an

increasing number of stoker fired furnaces are being equipped with water cooling. This has been carried to such an extent that in a few

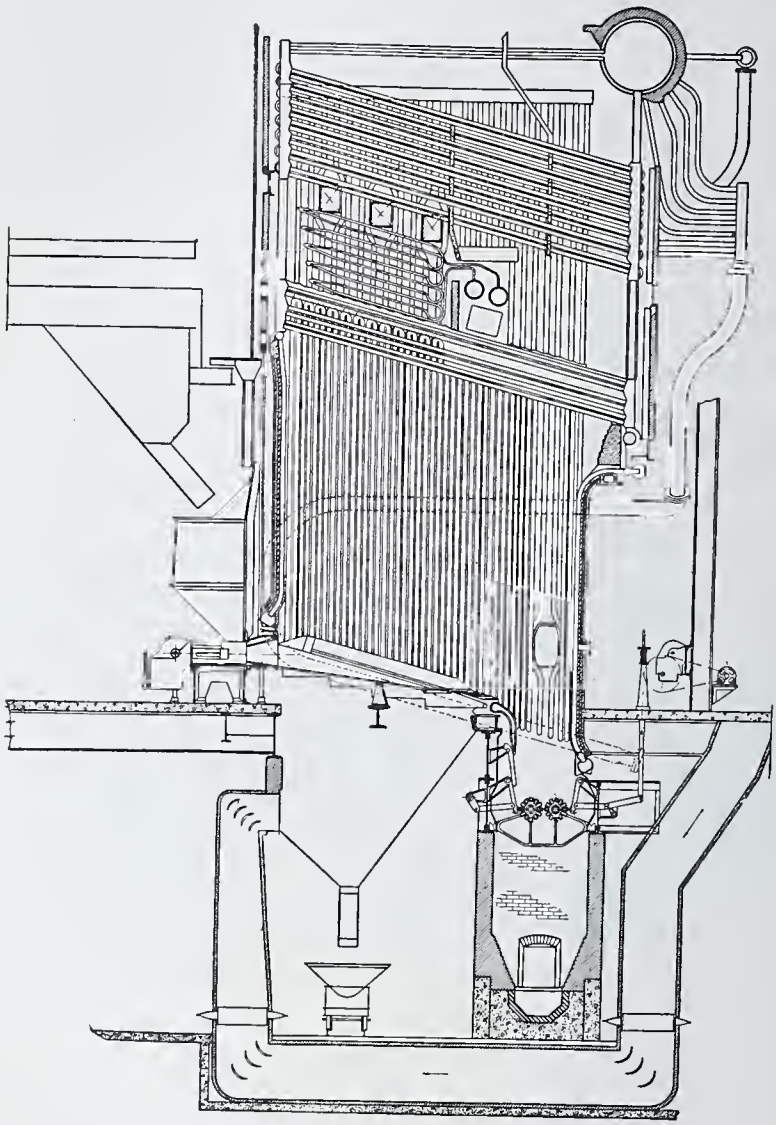

FIG. 6

cases the entire furnace is enclosed with water cooling and only very little refractory is exposed to the heat of the furnace.

Figure 6 shows an installation of a 2290 h.p. boiler with water cooling carried out to such an extent that even the walls adjacent to

the boiler tubes are covered with water cooled surfaces. A stoker 18 feet in length is used. Air zoning is provided so that any portion of the fuel bed is under control of the operator. Forced draft air, preheated to 450°F. will be used. It is expected this installation will be capable of capacities of 450 per cent of boiler rating. Such an installation should be comparable with the most modern pulverized coal installation.

Application of what we still regard in the line of refinements, such as air preheating, zoning and water cooling of the walls, is generally thought of only in connection with the large boiler units. This is

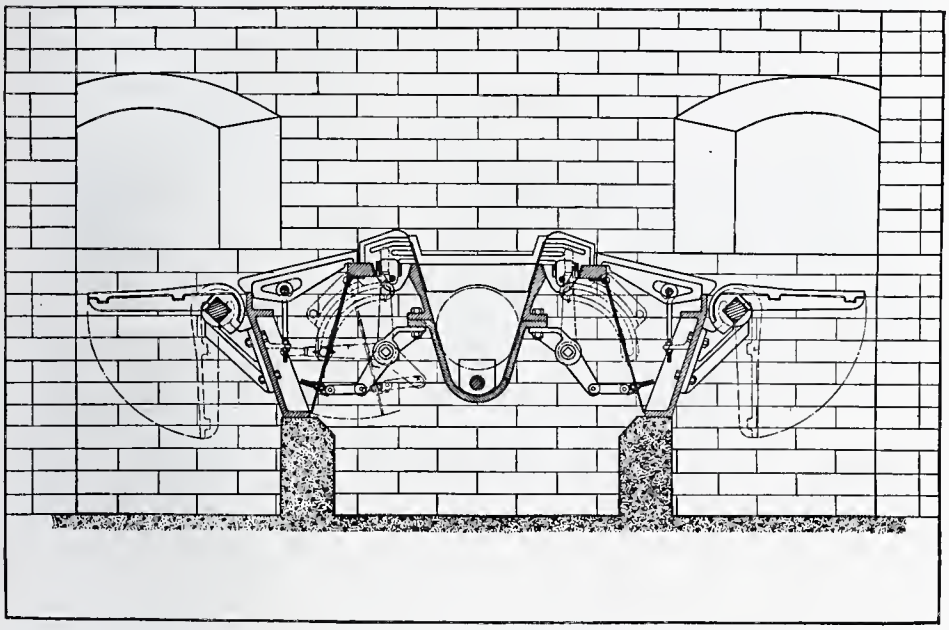

FIG. 7

not so for in a number of small industrial plants the advantages of these refinements are being enjoyed. Zoning of small underfeed stokers is not only an advantage, but is now becoming a necessity in view of the reduced maintenance and higher efficiencies which follow its use.

Figure 7 shows a cross section of a single retort side dumping type of stoker. Dampers separate the underfeed section where the fuel bed is heavy and where high pressure air is desired from the overfeed section where the fuel bed is thin. This prevents admission of excessive air through the thin portion of the fuel bed and also prevents

the blasting action on the coke and ash which is so productive of clinkers and destructive to stoker castings and wall refractories.

Preheated air has been applied to small stokers, although not so generally nor to such high degree as is found in larger stations. There is, however, no reason to believe that highly preheated air should not work as successfully with small units as with the larger ones, and we can expect to see its use increasing in the small plants.

The general use of water walls in small plants is hardly to be looked for at the present date. Nevertheless there will be, no doubt, an increasing number of installations as their benefits become known. They are particularly advantageous when placed in side walls of

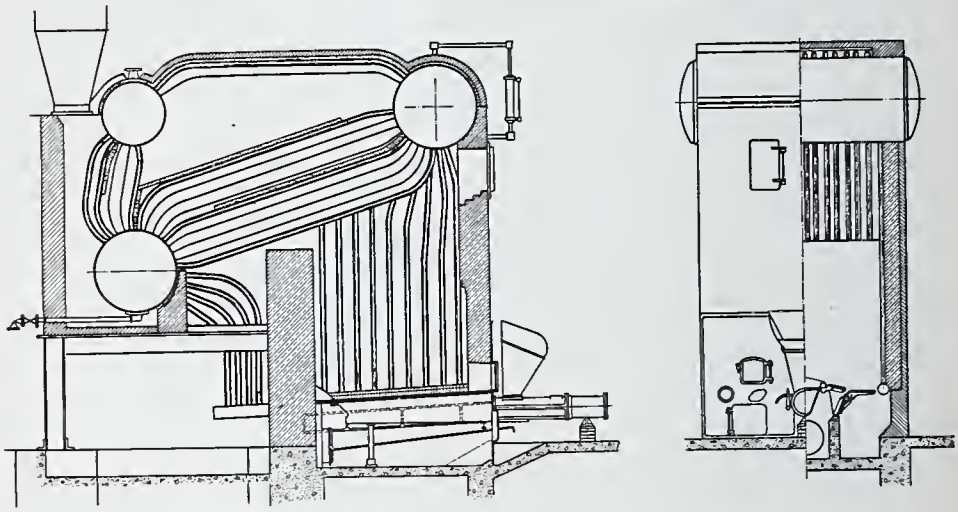

FIG. 8

furnaces equipped with the single retort side dump type of stoker. Here they prevent wearing out of walls due to fusing of ash and brickwork and the ordinary hard use that such portions of the brickwork are subject to. They permit the use of poor grades of fuel which could not ordinarily be considered on account of the difficulty in burning them without severe clinker trouble. In a Chicago laundry such an installation has been in operation for 2 years without a penny being spent for furnace maintenance. Figure 8 shows the installation.

I have attempted, in the foregoing, to point out the changing character of stoker applications and in making a comparison between stoker and pulverized coal fired boilers, this changing character

should be borne in mind and we should be sure that our comparison is based on installations of similar characteristics. There are several factors which will prevent making a definite comparison, even though the installation is made under exactly similar conditions. Operation, nature of the fuel used, character of the load and, probably the most important, plant personnel, prevent making a true comparison. We are too apt to point to a successful installation of pulverized coal and a poor installation of stokers, or vice versa, and so base our claim of the superiority of one type of firing over the other.

In selecting the type of firing to be used in a new plant, the engineer is confronted with the problem of determining how he can obtain the best return on the investment. He must determine which method will permit the generation of steam at the lowest net cost. Into this enters the following factors—first cost, operating charges, maintenance costs, efficiency and then, when all this is settled, the type of coals available and the nature of the load at the plant.

Definite comparisons are almost impossible due to the complexity of the factors involved. Let us consider an actual case of two plants, identical in size, type of load and coal available. Figure 9 shows cross sections of two 500 h.p. boilers, one stoker fired, the other fired with pulverized coal. These units are in two different plants under the same management. Their load is approximately the same, the type of load is the same and except for the fact that the pulverized coal fired furnace has air cooled walls, the conditions of installation may be considered equal. Exact detailed figures are not yet available for publication, but sufficient data are available to make an approximate comparison.

The first cost is in favor of stokers, with the stoker installation costing approximately $65.00 per horsepower, as against $70.00 for pulverized coal. The difference is mainly in the furnace cost so that if solid walls had been used for the furnace of the pulverized coal fired boiler then the first cost of each would have been more nearly equal.

Operation costs are equal; there being only two boilers in each plant a minimum crew of two men are carried on each shift.

Maintenance cost for the stoker and pulverizing equipment, while not covering a sufficient period to give an accurate average, will be about the same. Maintenance of the air cooled walls of the pulverized coal fired furnace will be considerably less than with the solid wall of the stoker fired furnace.

Efficiencies of these two plants are surprisingly on a par. During a 24-hour test of the stoker fired boiler, an efficiency of 83 per cent was obtained when handling the usual load of 160 per cent rating. The daily average efficiency is 76 to 77 per cent. While no tests have been run on the pulverized coal fired boiler, daily evaporation shows that there is little to choose between the two methods of firing. It should

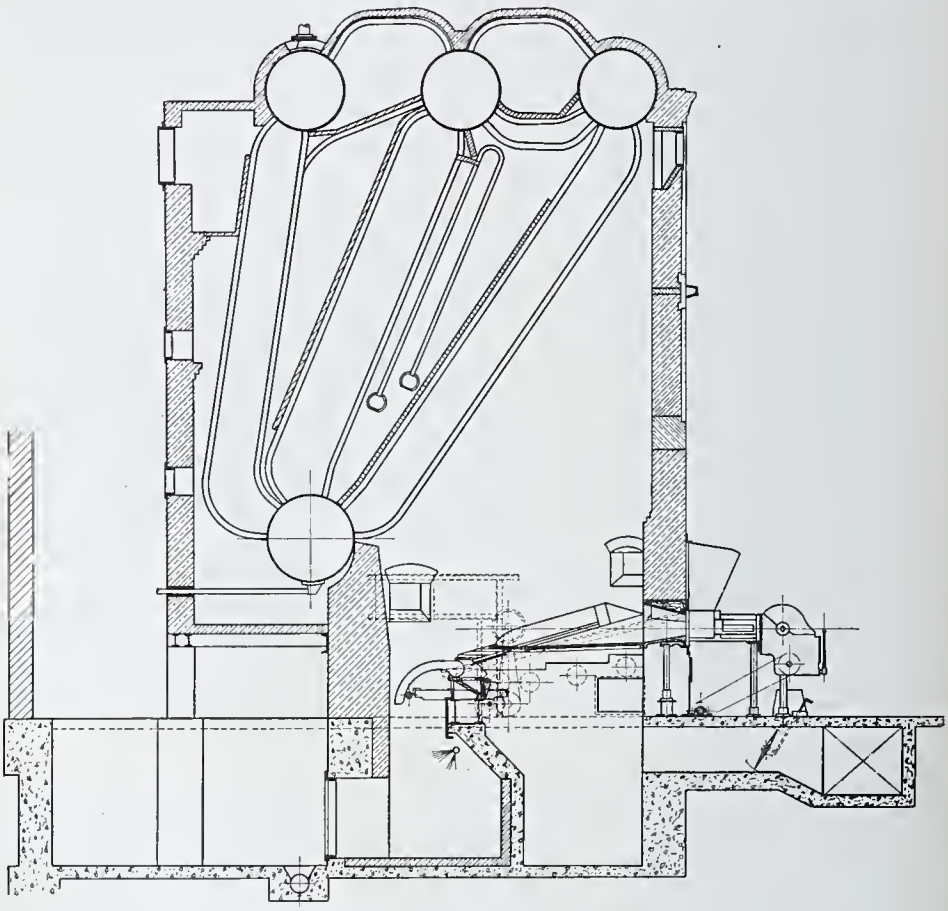

FIG. 9

be remembered that both of these plants have 24-hour loads so that no advantage accrues to the pulverized coal installation from this source. As far as these two plants are concerned, we are unable to choose between the two methods of firing. I believe these plants are unique in being installed and operated under so similar conditions.

In the matter of maintenance, there seems little to choose between stokers and pulverized coal. In the stoker report of the Prime

Movers Committee of the National Electric Light Association for 1927 to 1928, there is given an average figure for maintenance labor and material of 9.5 cents per ton of coal used. This covers all types of stokers and all types of coal. It should also be remembered that these are figures for the large central station type of plant which are usual y operating at higher ratings than is usual in industrial plants.

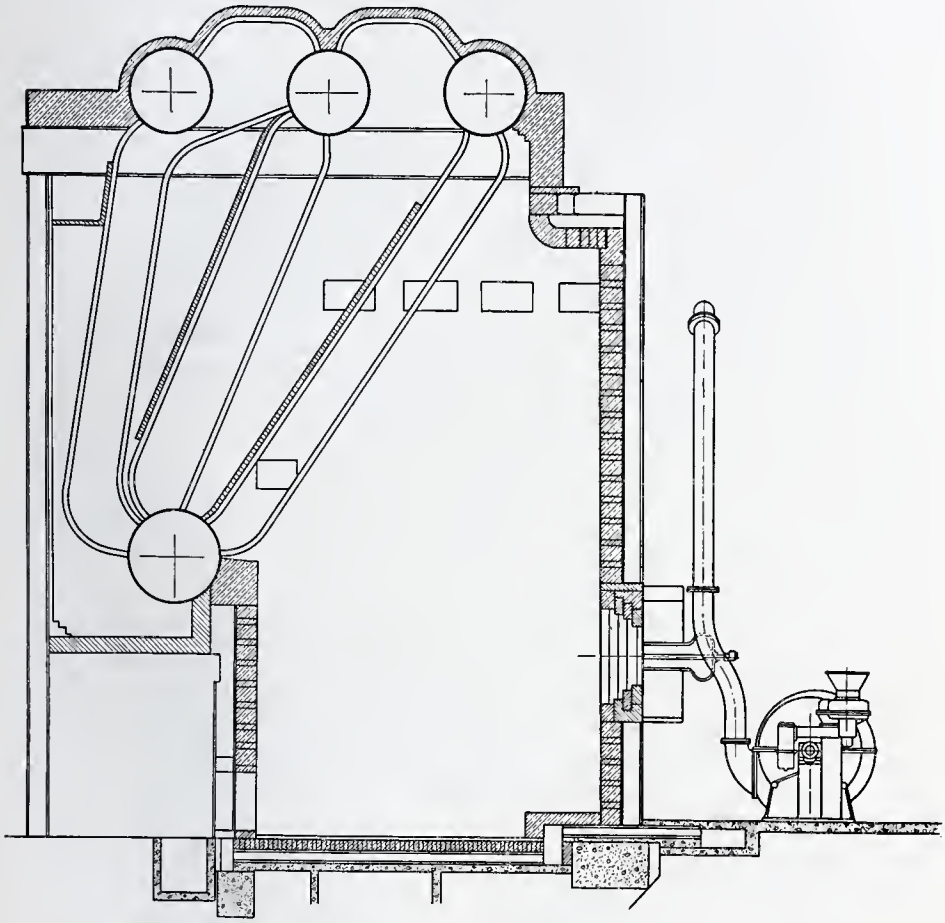

FIG. 9A

Experience with all types of stoker fired plants would indicate an average cost for maintenance material of from three to five cents per ton of coal burned, with labor averaging about the same amount. So we may consider the amount reported as very nearly representing average conditions throughout stoker fired plants.

The Prime Movers report on pulverized coal for 1927 to 1928

reports an average maintenance labor and material figure of 8.1 cents per ton of coal pulverized. This average does not include exceptional cases of exceedingly high maintenance, such as plants where anthracite is pulverized with maintenance as high as 51.7 cents per ton, or of very low maintenance where lignite is pulverized with a maintenance cost of 3.7 cents per ton. There seems, therefore, very little to choose between the two types of firing on the score of maintenance.

When considering efficiencies we are apt to think of the pulverized coal plant as being more efficient than stoker fired plants. This is probably due to reported savings in plants which have been changed from stoker to pulverized coal firing. In such cases the higher efficiency may be due to improved conditions under which pulverized coal is installed, also comparisons are usually between obsolete stoker equipment and modern pulverizing equipment.

Higher efficiencies are reported more often from pulverized fuel fired plants than from stoker fired plants and this leads to the common idea that pulverized fuel firing is more efficient in all cases. Here again we must make sure of our facts and in justice to both systems be sure conditions of installation and operation are really comparable.

It must be admitted, however, that where load conditions are such that there are long banking periods, the standby loss with pulverized coal is less than with stokers.

Claims are made by the adherents of both methods of firing regarding the superiority of one or the other as regards flexibility. It is questionable whether their claims are well founded. Let us take the case of two drop forge plants of almost equal boiler capacity. Here we have a very rapidly fluctuating load. The two flow meter charts (Fig. 10) illustrate very well the conditions under which these plants run. One plant is equipped with pulverized coal, while the other is stoker fired. The loads in both cases change rapidly from 50 to 200 per cent of boiler rating, yet either method of firing handles the load with equal facility. It would be difficult to distinguish from an examination of the charts which method of firing was used.

The type of fuel which is best used with stokers and pulverized coal is an interesting study and must receive consideration when selecting the method of firing. Stokers permit greater latitude in selection of coal than does hand firing. Likewise pulverized coal firing permits greater latitude than stokers.

Let us consider how the type of fuel available affects the selection

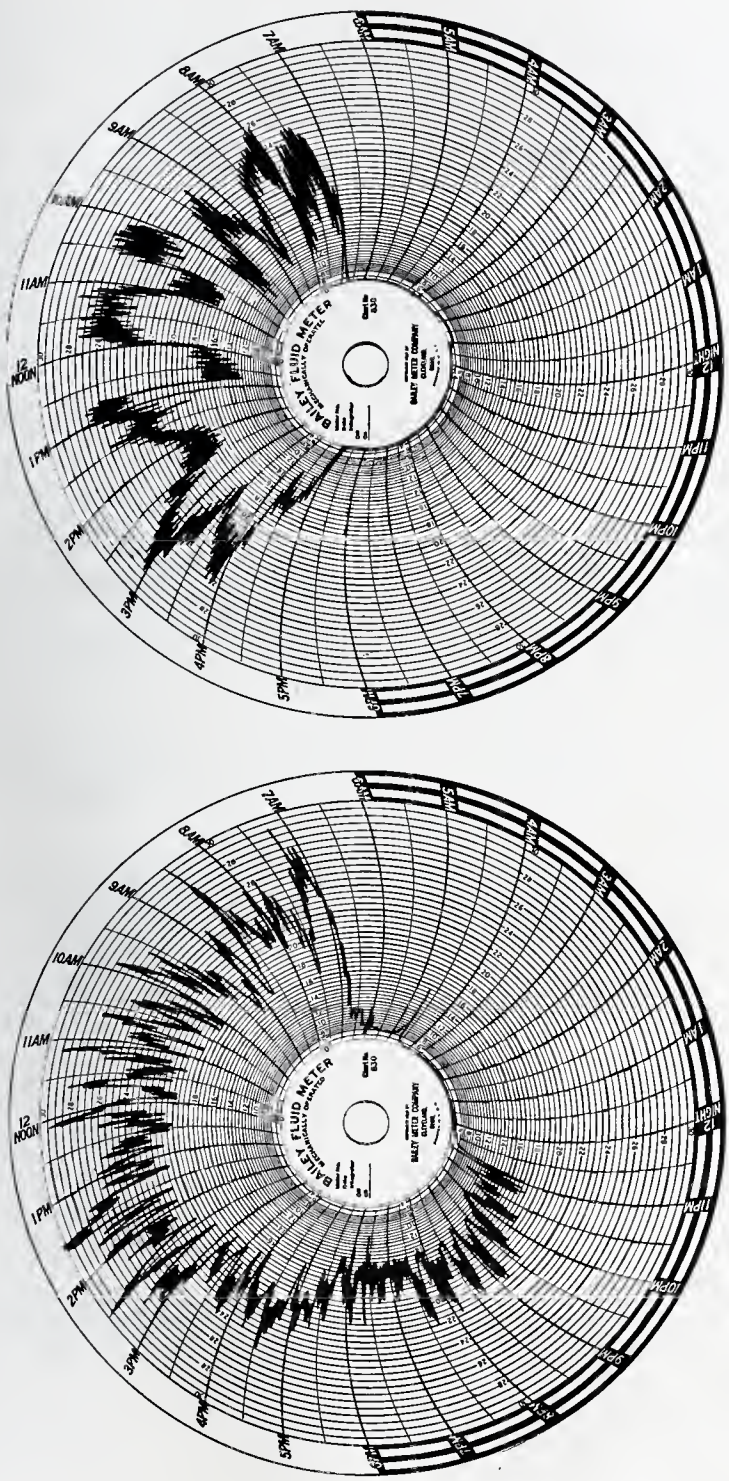
BAILEY FLUID METER
7AM
8AM
9AM
10AM
11AM
12 NOON
1PM
2PM
3PM
4PM
5PM
6PM
7PM
8PM
9PM
10PM
11PM
12 MIDN
1AM
2AM
3AM
4AM
5AM
6AM

FIG. 10

of stokers. Eastern bituminous coals, comprising the entire West Virginia, Pennsylvania and Kentucky fields, are handled on stokers with very little trouble. Only the poorer grades of these coals, where sulphur is high and the ash has a low fusing point, are troublesome and even these can be handled with stokers with proper furnace design. I refer to a furnace properly equipped with water or air cooled surfaces of sufficient area to reduce the furnace temperature at such points where refractories do not ordinarily withstand the severe service imposed on them. Low ash coals, that is coals with less than 5 per cent ash, should be avoided with stoker firing for they do not provide sufficient protection to the grate surface.

Western coals of the Ohio, Illinois and Iowa fields, are being successfully handled on underfeed and traveling grate stokers. With these coals more care must be taken to provide a furnace designed to properly control furnace temperatures and protect refractories.

Now, all these coals are being successfully burned in pulverized coal installations. It is interesting to note that the coals which give the best results with stokers usually give the best results with pulverized coal. At the time when stokers came into general use it was considered that a saving could be made on account of the ability of the stoker to handle low grade coals which could not be handled by hand firing. The fallacy of attempting to save money by buying poor coal has been proven many times with stokers.

You hear the same remarks regarding furnaces burning pulverized coal, that is they are able to handle poorer coals than stokers. Our information to date would indicate that the best coals obtainable give the best results with pulverized coal firing. The apparent advantage which pulverized coal firing seems to have in this ability to use low grade coals is due almost entirely to the fact that the furnaces have been designed with the definite object in view of handling these coals. The advantage which pulverized coal firing seems to have I do not believe can be maintained if equal care is given and equal expense invested in the installation of stokers. The application of water and air cooled walls will solve, to a great extent, the difficulties of handling Western coals with stokers.

In conclusion, it is my opinion that the art of burning bituminous coals has reached that point where it is difficult to choose between pulverizers and stokers.

Owing to the activity and novelty of pulverized coal firing, attention and efforts have been concentrated on its problems, with the

result that advances have been made rapidly and possibly to a point beyond that to which stokers have been carried. Stoker design and development, not being such a novel problem, have not been receiving the same attention. Now revived interest has resulted in remarkable advance in stoker design and application. We have to thank those pioneers in pulverized coal furnace design for the awakening of stoker designers and I predict that we will directly see stoker installations of increasing number making use of the very factors which have contributed to the success of pulverized coal firing and which will produce results in every way comparable with pulverized coal.

DISCUSSION

H. L. RICHARDSON (West Kentucky Coal Company, Paducah, Ky.): In reference to the statement that the lowering of combustion temperatures has been found advisable for the most economic transfer of heat to the boiler, I would like to ask Dr. Rosin if tests have been made that determine, within reasonable range, the most economical combustion chamber temperature for the best transmission of the heat?

DR. ROSIN: The most economic temperature lies at the point where the time for the conversion to combustion readiness becomes too long. I mentioned that it is not advisable to lower the temperature below 1,200°C., because then the time element gets too great and the combustion is prolonged.

MALCOLM MACFARLANE (New York Central Lines, New York): I would like to ask Dr. Rosin whether he has any results on low volatile, medium volatile, and high volatile coals, with regard to the most economical combustion.

DR. ROSIN: The results I obtained concern the dark brown coal, which is a very high volatile coal, for when dried it contains about 50 per cent of volatile matter. I made a test with our Westphalia bituminous coal, of which the content of volatile matter lies between 25 and 35 per cent. I also made tests with semi-bituminous with a content of volatiles of 7 per cent. So I think I tested every kind of coal produced.

MR. MACFARLANE: Do you get better results with the higher volatile than with the lower volatile coal?

DR. ROSIN: It depends on the analysis of the volatile matter. If you have in the volatile matter hydrocarbons which are very difficult to burn, the high volatile matter will be of less use than the low per cent volatile matter.

PROFESSOR E. A. ALLCUT (University of Toronto, Toronto, Canada): I was very much interested in what Dr. Rosin said about the desirability of using low

furnace temperatures. That is fairly obvious from a practical standpoint. It is well known that radiation is an extraordinarily efficient means of transmitting heat from the place where the heat is generated to the place where it has to be used. As, according to the Stefan-Bolzmann law, the radiation grows with the fourth power of temperature, I would like to know how Dr. Rosin considers that this law and low furnace temperature work together.

DR. ROSIN: We cannot speak about an average temperature in the combustion. I mentioned that the combustion itself takes place at the theoretical flame temperature, the highest temperature we can obtain. From this limit temperature the radiation takes place to the surrounding walls in accordance with the fourth power of temperature.

The low temperature is the temperature with which the gas goes out of the furnace, while the combustion temperature determines the radiation. My opinion is that the temperature at which combustion takes place is not influenced, at least not momentarily, by variation in the rate of radiation.

MARTIN FRISCH (Combustion Engineering Corporation, New York): Dr. Rosin in one of his charts called attention to the fact that at a combustion rate of around 1,400 B.t.u. per cubic foot the carbon loss as calculated by his method would be around 4 per cent, and at 40,000 B.t.u. per cubic foot around 11 per cent. Both of these figures are much higher than customarily expected of a plant designed for American practice. What is the maximum combustion rate that might be expected from a furnace that is calculated in accordance with his figures? In other words, are combustion rates of the order which engineers are working to now, namely, around 30,000 B.t.u. per cubic foot, the limit that his calculations indicate, or by his method does he predict higher combustion rates?

DR. ROSIN: I said 40,000. With a heat liberation of 40,000 B.t.u. according to my calculation the loss of unburned dust would be nearly 4 per cent.

MR. FRISCH: That still does not change my question because 4 per cent is still a figure that is higher than we desire. That would place the limit in accordance with our practice at 40,000 B.t.u.

DR. ROSIN: I mentioned that the method of calculation certainly gave results somewhat too high. I should like to say that these figures are to be considered as the upper limits of the loss of carbon with a heat liberation of 40,000 B.t.u.

MR. FRISCH: From that are we to infer that 40,000 B.t.u. per cubic foot is the maximum limit at the present time that is possible?

DR. ROSIN: I should not say that for it depends, as I mentioned, on the loss which is bearable for the plant. For instance, if you have a very cheap coal you may permit a loss much higher than if you have a very expensive coal. It depends on the price of the coal and on the degree of use of the power plant. It also depends on the load of your power plant and the installation costs.

MR. FRISCH: That answers my question.

W. J. WOHLENBERG (Yale University, New Haven, Conn.): I suppose that I can be more in sympathy with the work that Dr. Rosin has done than most of you, because for the past four years I have been thinking somewhat along the same lines. We have been studying at Yale the problem of radiation from the pulverized fuel flame, and in that pursuit have dealt with many of the phases in much the same way that Dr. Rosin has.

Dr. Rosin has studied some conditions which influence the rate of energy release. We started in our work by fixing the rate of burning of the oxygen, i.e., the union of the oxygen with the fuel particles. We assumed uniform furnace conditions throughout. Then we used particle size distribution curves very similar to those of Dr. Rosin. When we consider that these factors (and some others which I cannot discuss now) set up an equation which involves a rate of energy liberation, the rate of heat discharged to the furnace walls, and the rate at which heat is carried away by the gases, we find out what the mean temperature of the gases escaping the furnace should be for a given rate of energy release in the furnace cavity.

These radiation means of a furnace temperature depend, among other things, on the furnace symmetry, i.e., on the extent of the refractory and cold surfaces in the furnace walls. I understood Dr. Rosin to say in his paper that the flame temperature (not the mean furnace temperature) could be affected only a very small amount by the rate of heat discharged from the flame. This is one point on which I should like to get a little more light.

CHAIRMAN HOWE: Would you like to undertake to answer that now, Dr. Rosin?

DR. ROSIN: Mr. Wohlenberg asked about the two temperatures I mentioned in the furnace. I mentioned two temperatures. I said that one temperature is the flame temperature and the other temperature is the mean gas temperature. I think the temperatures are different. I said that theoretical combustion has to take place at the theoretical temperature, for the combustion itself is a primarry process and the radiation process is the secondary process. Therefore, the combustion itself may not be influenced in the beginning by the radiation of heat to the walls; only the secondary process of radiation diminishes the temperature of the gases.

I do not know whether I am right, Mr. Wohlenberg, in the understanding of your question.

MR. WOHLENBERG: I think you are.

ADAPTATION OF PULVERIZED FUEL TO MARINE BOILERS

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and

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Foreword

Ever since the early experiments conducted by Admiral B. F. Isherwood, made in 1867, the problem of adapting pulverized fuel to marine practice has been of keen interest to marine engineers.

The early attempts were confined chiefly to utilization of pulverized or granulated coal as an auxiliary fuel over a hand-fired grate fire. The results obtained were in the main uneconomical, due chiefly to the fact that the art of mechanical fuel reduction or pulverization was not sufficiently advanced and the idea of flame turbulence had not been propounded.

It is not the intent of this paper to review the entire history of the attempts to make pulverized fuel seagoing, but rather to record the recent developments and the immediately preceding experiments which eventually led up to a successful marine installation.

The United States Shipping Board owns and operates a large fleet of ships, some of which have been converted to Diesel motor drive but the greater number are steam driven, some burning oil and others coal. All have certain advantages and disadvantages. Conversion from steam to Diesel drive is an expensive undertaking. The over-all efficiency of a hand-fired coal burning boiler with expert firemen seldom exceeds 65 per cent and even this figure diminished at higher rates of combustion and, furthermore, expert and conscientious firemen are not only hard to find but difficult to retain and while fuel oil prices at present are low in the United States they are sometimes very high, the fluctuation being as much as 100 per cent.

Liquid fuel, for a number of reasons, such as ease of bunkering,

reduced operating personnel and simplicity of operation, is particularly well adapted to marine use but the wide fluctuation in price, the need of conservation of a natural resource, makes it most desirable that a competitive fuel be available—a fuel that is plentiful, that can be secured at a reasonable price and can be handled with approximately the same ease as liquid fuels.

The Fuel Conservation Committee of the Merchant Fleet Corporation of the U. S. Shipping Board, to whom is entrusted the task of reducing the fuel costs of the American Merchant Marine, recognized

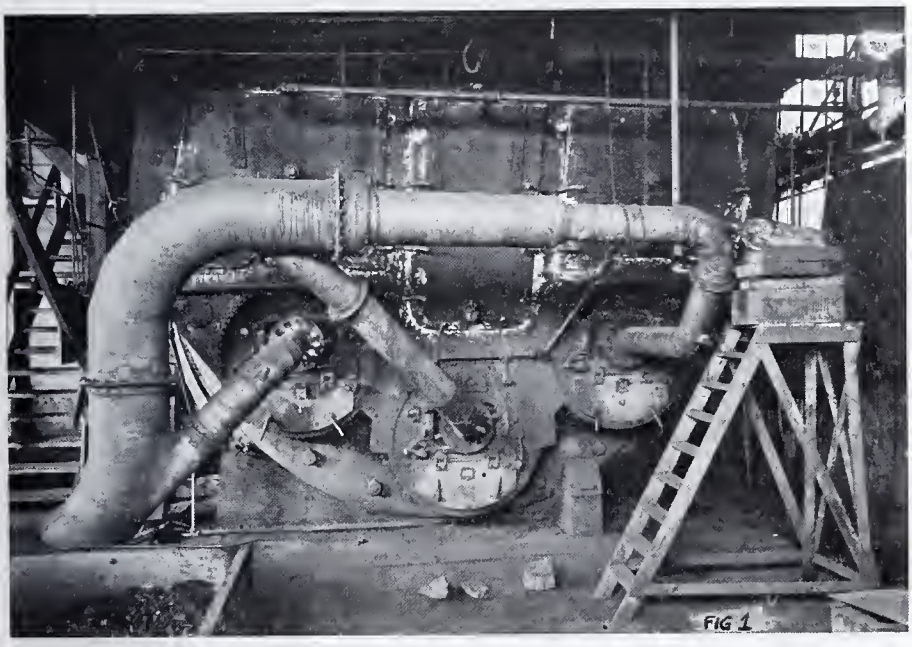


FIG. 1. CONVENTIONAL STREAM LINE BURNER INSTALLATION IN SCOTCH MARINE BOILER

this problem and instituted the initial tests of pulverized coal burning with the object of developing an installation suitable for operation on a seagoing vessel.

1921 TESTS

It was decided to make the tests on a Scotch marine boiler inasmuch as a majority of the cargo carriers are equipped with this type of boiler and because the use of pulverized coal in the small water-cooled furnaces of these boilers seemed to offer a more difficult problem than the refractory lined furnaces of water tube boilers.

The first test was made at Chester, Pa., in 1921, using the conventional stream line burner. This installation is shown in Figure 1. The maximum rate of combustion that could be maintained was 2.5 pounds of coal per cubic foot of furnace volume or a maximum heat release of 32,000 B.t.u. per cubic foot per hour. The boiler efficiency at this rate was only 54 per cent.

The results of this series of tests were far from satisfactory and did not justify in any way further consideration of the problem at that

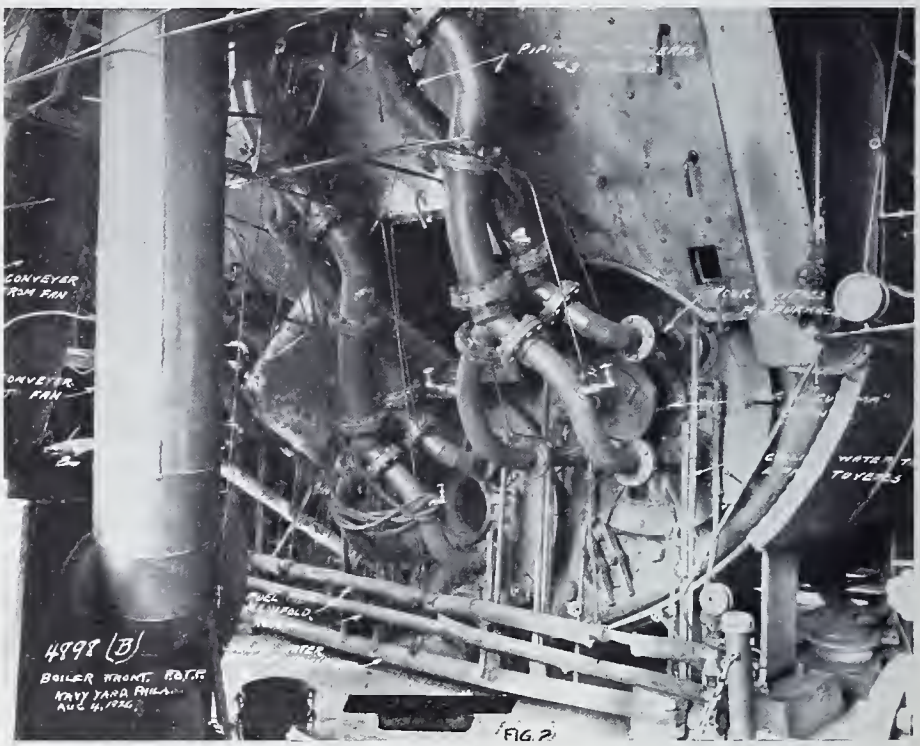


FIG 2

time. The basic principles which govern successful combustion in limited furnace volume had not been determined at that period.

1926 TESTS

Between 1921 and 1925, however, considerable advancement was made in the art of using pulverized fuel for steaming purposes, and the effect of flame turbulence and fineness of fuel grind began to be appreciated. This stimulated the interest in utilization of pulverized fuel for marine purposes which had lain dormant since the 1921

tests. Accordingly, the Fuel Conservation Committee of the U. S. Shipping Board, under the leadership of Captain C. A. McAllister and Captain R. D. Gatewood, decided to reinstitute the development test work along these lines.

To this end, coöperation was requested of and granted by the Bureau of Engineering of the U. S. Navy and as a result the subsequent development Test Plant work has been conducted at the Fuel Oil Testing Plant at the Navy Yard, Philadelphia, Pa., which is a

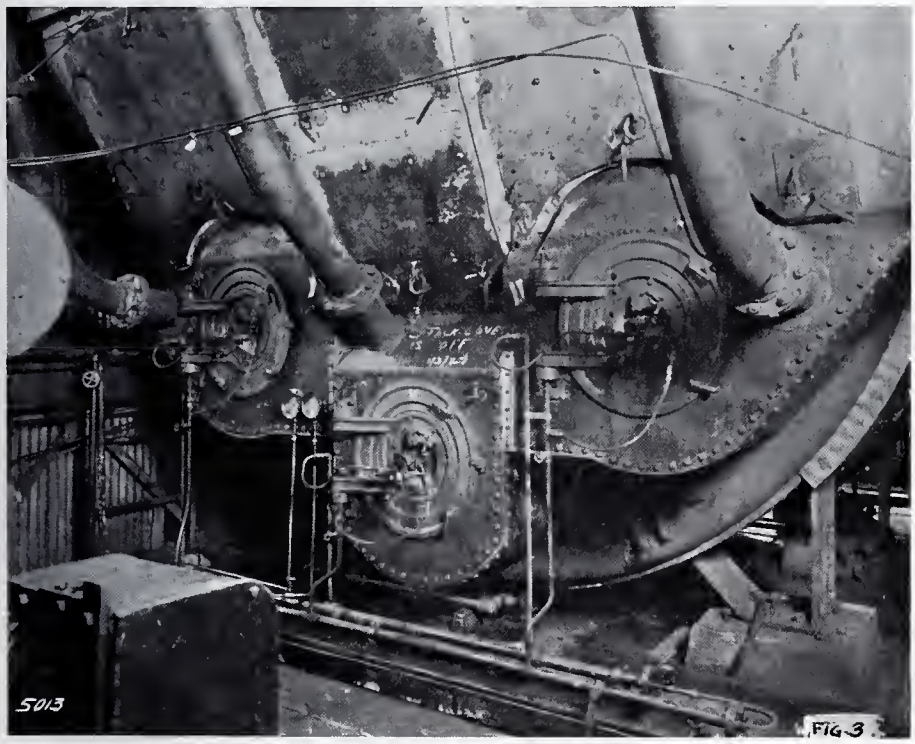


FIG. 3. EXTERIOR OF DOUBLE FRONT WITH BURNERS, COAL CONVEYOR PIPES AND OIL CONNECTION INSTALLED

laboratory maintained by the Bureau, where practically every device used in the fireroom of a Naval vessel or connected with boiler operation is subject to test.

It was early decided that equipment operating on the "unit system" would be used on future tests and that a turbulent type burner was required. Although the initial series of tests conducted did not produce a seagoing installation, they did demonstrate the feasibility of burning pulverized coal in the limited furnaces of a Scotch marine

boiler. A combustion rate as high as 6.19 pounds of coal per cubic foot of furnace volume was reached for short periods with a heat release of 88,330 B.t.u. per cubic foot furnace volume and a boiler

1	Run number	50 (a)	50 (b)	50 (c)	50 (d)	50 (e)
3	Boiler water heating surface, sq. ft.	2,555	2,555	2,555	2,555	2,555
4	Original furnace volume, cu. ft.	482.90	482.90	482.90	482.90	482.90
5	Present furn. vol. cu. ft.—after installation of burner brick work	469.98	469.98	469.98	469.98	469.98
30	Fuel oil testing plant no. of coal sample	SC 878	SC 879	SC 880	SC 881	SC 882
31	Fixed carbon	72.1	71.0	71.7	72.3	70.0
32	Volatile matter	20.1	20.2	20.0	20.3	21.2
33	Moisture	2.1	2.8	2.6	2.4	2.8
34	Ash	5.7	6.0	5.7	5.0	6.0
35	Total	100%	100%	100%	100%	100%
36	Sulphur—separately determined	1.1	1.7	1.6	1.3	1.8
37	Carbon (C)	81.8	80.7	81.4	82.3	80.6
38	Hydrogen (H)	5.0	4.9	4.9	4.9	4.9
39	Sulphur (S)	1.1	1.7	1.6	1.3	1.8
40	Nitrogen (N)	1.4	1.3	1.3	1.3	1.4
41	Oxygen (O)	5.0	5.6	5.2	5.2	5.4
42	Ash	5.7	5.8	5.6	5.0	5.9
43	Total	100%	100%	100%	100%	100%
44	Calorific value, B.t.u.	14,460	14,303	14,377	14,565	14,285
70	Retained on No. 40 sieve					
71	Retained on No. 50 sieve, passing No. 40 sieve	1.4	0.3	0.7	0.8	0.7
72	Retained on No. 70 sieve, passing No. 50 sieve	2.5	1.4	2.2	2.5	2.5
73	Retained on No. 100 sieve, passing No. 70 sieve	4.5	3.6	4.0	4.2	4.0
74	Retained on No. 140 sieve, passing No. 100 sieve	4.5	4.7	4.8	4.4	5.1
75	Retained on No. 200 sieve, passing No. 140 sieve	8.8	8.8	8.7	8.4	8.7
76	Retained on No. 300 sieve, passing No. 200 sieve	9.5	10.2	9.5	10.3	9.4
77	Passing No. 300 sieve	68.8	71.0	70.1	69.4	69.6
90	Carbon dioxide, % CO_2	16.2	16.7	17.0	17.1	16.3
91	Oxygen, % O_2	2.65	2.0	1.7	1.6	2.8
92	Carbon monoxide, % CO	0.005	0	0.5	0.79	0.13
93	Nitrogen, % N_2	81.145	81.3	80.8	80.51	80.77
98	Smoke—Ringelman scale	1/4	1/4	1/4	1/2	1 to 2
110	Steam press. on boiler lbs./sq. inch absolute	190.3	190.0	190.8	191.5	192.1
116	Draft at base of smoke pipe	−0.20	−0.35	−0.34	−0.33	−0.34
137	Temp. secondary air entering burners, °F.	215.8	216.7	216.1	212.2	211.2
139	Temp. primary air entering burners, °F.	144.5	147.6	140.6	140.5	137.4
144	Av. temp. gases leaving heater, °F.	415.1	451.0	504.2	531.6	538.7
157	Av. temp. gases before heater, °F.	501.4	550.9	599.0	628.8	640.0
147	Temp. steam calorimeter	306.7	306.7	306.9	307.3	307.7
148	Temp. sat. steam in boiler at boiler press.	377.72	377.6	377.9	378.3	378.5

FIG. 4A. ABRIDGED DATA SHEET SHOWING PERTINENT DATA

efficiency of 68.7 per cent without air preheater or superheater. The principal reasons for the failure of this installation, which is shown in Figure 2, were uneven distribution of fuel to the burner nozzles and

151	Temp. of feed water entering boiler, °F	208.4	208.9	210.2	205.5	210.4
169	Mill speed, r.p.m	33.4	33.4	33.4	33.4	33.4
171	Distributor speed, r.p.m	1,220.0	1,220.0	1,234.0	1,155.0	986.2
175	Duration of run, hours	48	48	48	48	48
176	Coal fired—total lbs. to mill	57,859	66,395	76,767	86,422	94,808
177	Actual total evap. of B.W.H.S., lbs	615,315	718,878	811,266	906,293	935,762
192	Coal fired per hour, lbs	1,205.4	1,383.2	1,599.3	1,800.5	1,975.2
193	Coal fired per sq. ft. B.W.H.S. per hour, lbs	0.47	0.54	0.63	0.705	0.77
194	Coal fired per furnace per hour (assuming equal distribution), lbs	401.8	461.1	533.1	600.16	658.4
195	Coal fired per cu. ft. of furnace vol. per hr	2.565	2.944	3.403	3.83	4.202
197	B.t.u. fired per hr. per sq. ft. B.W.H.S	6,821.9	7,743.4	8,999.3	10,264.0	11,043.3
198	B.t.u. fired per hr. per cu. ft. of furn. vol	37,086.9	42,096.0	48,923.7	55,798.8	60,036.0
199	Actual evaporation of B.W.H.S. per hr., lbs	12,819.06	14,976.6	16,901.0	18,881.10	19,495.0
200	Quality of steam, %	99.81	99.81	99.81	99.83	99.84
201	Actual evaporation per hr. corrected for moisture	12,794.7	14,948.1	16,868.9	18,849.0	19,463.8
202	Factor of evaporation	1.0520	1.0515	1.0502	1.0551	1.0501
203	Equivalent evaporation of B.W.H.S. per hr., lbs	13,460.0	15,717.9	17,715.7	19,887.6	20,438.9
204	Equiv. evap. per sq. ft. B.W.H.S. per hr., lbs	5.27	6.15	6.93	7.78	8.00
205	Equiv. evap. per lb. of coal as fired, lbs	11.166	11.36	11.077	11.05	10.348
206	Boiler horse power, b.h.p	390.1	455.5	513.5	576.5	592.4
207	Per cent rating, %	152.7	178.3	201.0	225.6	231.8
211	Equiv. steam per hr. for driving feeder	7.9	8.93	6.35	5.5	3.76
215	Equiv. steam per hr. for driving distributor	14.5	14.10	15.51	15.3	9.96
217	Equiv. steam per hr. for driving primary air fan	99.2	100.62	110.5	106.7	137.2
218	Equiv. steam per hr. for driving reduction gear and mill	846.0	846.0	846.0	846.0	846.0
219	Equiv. steam per hr. for driving second, air fan	32.5	52.7	84.3	140.4	186.1
220	Equiv. steam per hour for driving feed pump	320.5	374.4	422.5	472.0	487.4
240	Per cent excess air over theoretical amt. required for complete combustion	13.32	9.98	4.34	2.077	10.81
250	Total unavoid. heat losses—actual—with double front b.t.u	1,034.9	1,008.4	996.4	1,067.1	1,038.6
269	Heat loss chargeable to B.W.H.S. and burners, B.t.u	2,879.3	2,751.7	2,927.8	3,071.6	3,564.0
271	Heat loss chargeable to furnace and burners, B.t.u	2,464.0	2,190.3	2,236.8	2,307.0	2,683.9
272	Heat loss chargeable to B.W.H.S., B.t.u	415.3	561.4	691.0	764.6	880.1
273	Heat absorbed by boiler per lb. coal, B.t.u	10,835.5	11,023.74	10,749.1	10,722.9	10,041.7
277	Overall efficiency of B.W.H.S., furnace, air heater and burners, %	74.93	77.08	74.77	73.62	70.32
278	Efficiency of B.W.H.S., %	98.85	99.27	96.46	95.82	95.07
279	Combined efficiencies of furnace and burners	81.65	83.52	83.28	82.91	79.74
280	Combined efficiencies of B.W.H.S., furnace, air heater, and burners, eliminating unavoid. losses, %	80.7	82.92	80.33	79.44	75.81
281	Saving effected by air heater, %	4.95	5.18	4.88	5.21	5.41
285	Fireroom efficiency inside F.O.T.P. Scotch boiler—fireroom bulkeads	69.37	72.5	70.28	69.50	66.23

FIG. 4 B. ABRIDGED DATA SHEET SHOWING PERTINENT DATA

lack of proper control over the air pressures. The entire supply of air for combustion was primary air and as the pulverizer was an air swept mill, any attempt to regulate the air supply affected both the turbulence nd the character of the grind.

1927 TESTS

In the meantime, the Peabody Engineering Corporation had produced a compact turbulent burner which incorporated the advantages of the equipment employed on the aforementioned tests but which was free of its numerous disadvantages, such as complexity of piping, lack of air control, etc. Figure 3 shows the Peabody burners installed on the test boiler. A high speed hammer or impact pulverizer was used for the first set of runs but a slow speed ball mill manufactured by the Kennedy-Van Saun Manufacturing and Engineering Company was subsequently installed. This equipment was tested very thoroughly and upon the results of these tests the installation on the S. S. *Mercer* was subsequently based. Considerable preliminary work was necessarily accomplished and many valuable lessons were naturally learned before the members of the Fuel Conservation Committee and the Fuel Oil Testing Plant were satisfied that an installation could be made in a seagoing vessel. It was soon established that fineness of pulverization was essential for good results, that proper regulation of primary air at the mill must be provided for and that the coal must be equally distributed and equal quantities fed to each of the three furnaces.

240-HOUR TEST

Very excellent results were obtained with this last installation and it was decided to conduct a test of ten days' duration at varying rates of combustion to simulate the trans-Atlantic run of a cargo carrier. The coal firing rate was changed after each 48 hours of steaming starting with 1,200 pounds of coal per hour and finishing with 2,000 pounds. All the data of a regular boiler evaporative test were taken and a careful record was kept.

Comparatively little trouble was experienced in continuing the run, minor mechanical difficulties were encountered but at no time was it necessary to stop the test. The most serious trouble was due to moisture in the coal which was stored out of doors and which became thoroughly wet during the heavy rains.

A tabulation of the principal data obtained during this run are shown in Figures 4a and 4b. The heat liberated per cubic foot of furnace volume ranges from 37,087 B.t.u. at 1,200 pounds of coal per hour to 60,036 B.t.u. at 2,000 pounds. The over-all (boiler, furnace and burners) efficiency on the basis of coal "as fired" is a maximum of 77.08 per cent at 1,400 pounds per hour and a minimum of 70.3 per cent at 2,000 pounds per hour.

"MERCER" INSTALLATION

The Fuel Conservation Committee made a careful study of the results of this test, decided that they warranted trial on a seagoing vessel, and the S. S. *Mercer* was accordingly allocated for this pupopse by the Shipping Board. The *Mercer* is a 9,500 ton cargo vessel, built in 1920 and operated intermittently as an oil burner until laid up in March, 1927. She was converted to burn pulverized fuel at the Maryland Dry Dock and Shipbuilding Co., Baltimore, in October, 1927. The pulverized coal equipment consists of two slow speed tube mills having a capacity of 3,600 pounds per hour each, supplied by the Kennedy-Van Saun Manufacturing and Engineering Company. There are nine (9) turbulent inside mixer type burners supplied by the Peabody Engineering Corporation. There are two (2) single roll coal crushers for reducing the coal to $1\frac{1}{2}$ inch-sizes and two (2) bucket type conveyors for elevating the coal from the lower bunkers to the crushers. The pulverizers and burners are practically identical with the equipment used in connection with the 240-hour test of the Scotch boiler at the Fuel Oil Testing Plant. The installation of the pulverized fuel plant necessary piping and coal bunkers were the only changes made in the vessel.

It was desired in fitting out the S. S. *Mercer* to have absolute reliability and to have a flexible arrangement which would take care of any emergency which might arise from break-down of the equipment. To meet these requirements the original installation was made permitting the feeding of any one, two, or all three of the boilers with either pulverizer and also the operation in parallel of the two pulverizers at reduced capacity.

Actual operation under this arrangement, however, was unsatisfactory owing to the enormous friction loss in the piping, the difficulty experienced in synchronizing the two primary air fans of the mills when attempting to operate them in parallel and the impossibility of distributing equal quantities of coal to each boiler. It was found

that any two of the boilers could supply all the steam required to operate the vessel at her rated speed, and it was therefore decided to rearrange the piping so that each mill supplied coal to one boiler, the center boiler remaining dead. With this arrangement, the S. S. *Mercer* steamed to sea on the first off-shore voyage of a seagoing vessel using pulverized coal as fuel. This same arrangement was

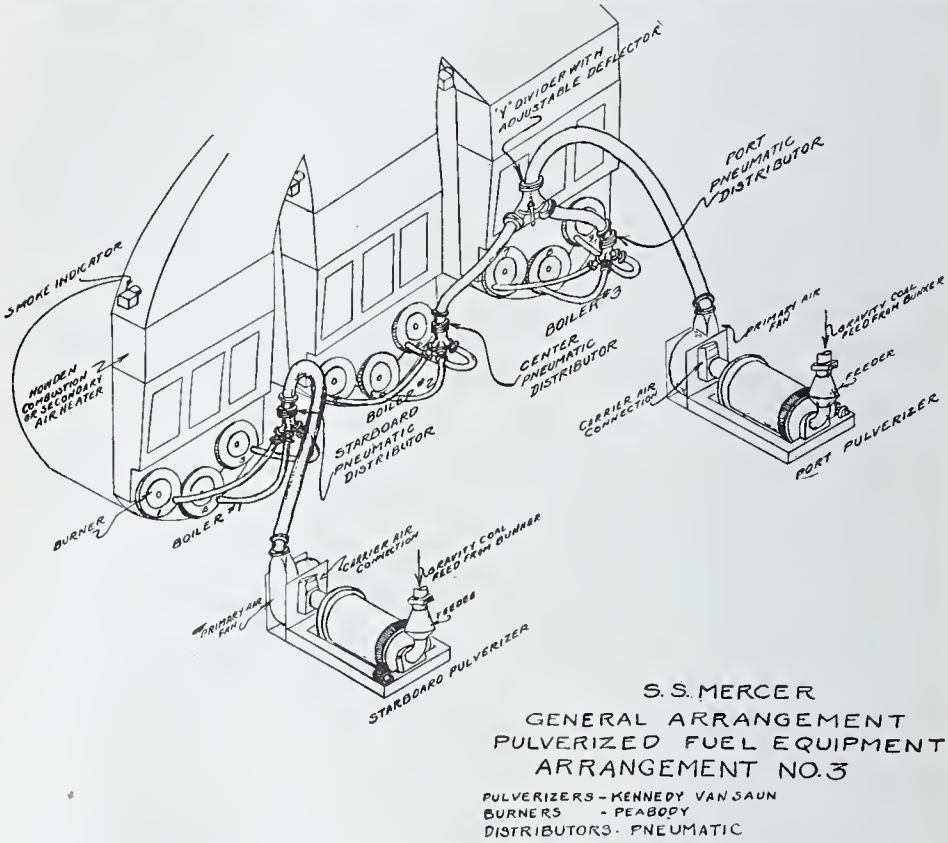


FIG. 5. S. S. MERCER. GENERAL ARRANGEMENT OF PULVERIZED FUEL EQUIPMENT, ARRANGEMENT NO. 3

Pulverizers—Kennedy and Van Saun. Burners—Peabody. Distributors—Pneumatic.

continued for the first three trans-Atlantic voyages and for the eastbound passage of the fourth voyage.

While this arrangement was satisfactory when using average grades of fuel, it was necessary to force the boilers when steaming with inferior grades of coal; moreover, the center boiler being dead, it was found that the ash from the wing boilers would fill the uptakes,

smokeboxes and even tubes of the center boiler, thus creating an unsatisfactory condition which was partially overcome by operating the center boiler with an oil fire in one furnace.

Experiments had in the meantime been conducted at the Fuel Oil Testing Plant with various types of distributors and one was developed which gave very satisfactory service. This distributor was installed and gave such good results in equalizing the fuel fired to the individual furnaces of a boiler that the installation on the *Mercer* was modified to permit one mill to feed two boilers while the other mill fed the third boiler. This is the arrangement under which the *Mercer* now operates and is shown in Figure 5.

S. S. "MERCER" PERFORMANCE

Since commissioning as a pulverized coal burner, the S. S. *Mercer* has completed six trans-Atlantic voyages and has kept up to her schedule, never missing a day in spite of the fact that a number of changes in her original installation have been made.

At the termination of each voyage of all vessels operated by the Shipping Board, a report is compiled by the Fuel Conservation Section that gives the main operating data and a summary of the fuel performance. Such a report for the first voyage of the S. S. *Mercer* is shown in Figure 6.

As stated above, at the time she was converted, no changes were made in the power plant aside from the actual substitution of pulverized coal in lieu of fuel oil. Under these conditions a reasonable check can be made by comparing her performance as a pulverized coal burner with the best performance obtained when using fuel oil. Such a comparison shows her best oil burning performance to be a voyage made exactly one year prior to her conversion. This voyage was made at ten knot speed with 10.4 per cent slip, at a mean draft of 18 feet, using 270 pounds of fuel oil per mile. If adjustments be made for the 0.67 knot lower speed, the 3.53 per cent greater slip, and the 3 feet 6 inches greater mean draft under which the first pulverized coal voyage was made, then the fuel per mile factor becomes 280 pounds per mile for the oil burning performance.

The conversion factor on a British thermal unit basis for oil and coal is 1.3. Therefore, the 280 pounds of oil per mile is equivalent to 364 pounds of coal, which, in turn, means that the thermal efficiency of the S. S. *Mercer* as a pulverized coal burner on her initial voyage was 96 per cent of that obtained on her best voyage made as an oil burner.

Form 7233

UNITED STATES SHIPPING BOARD

VOYAGE REPORT — **PORT OF** NEW YORK

S. S. "MERCER" — **OPERATORS** American Diamond Line — **VOYAGE No. VESSEL** 57 — **VOYAGE No. OPERATOR** 1

DESCRIPTION OF VESSEL

BUILDERS Federal S. B. Company — **TYPE** Cargo — **DESIGNED D.W.T.** 9500 (app)& 13,175

LENGTH B. P. 395'0" — **BEAM** 55'0" — **DRAFT** 27'4" — **SPEED** 11 — **AT** 90 **R. P. M.** — **PROP. PITCH** 13.4' — **DIA** 17'-0"

ENGINE G. E. Turbine — **H. P. RATED** 2,500 — **LAST OPENED** 9-1927 — **LAST DRY DOCK** 9-1927 — **ANN. INSP. DUE** 10-1928

No. BOILERS 3 — **TYPE** Scotch — **SUPPH'S. TYPE** Milne — **FUEL TYPE** pulverized coal — **BURNER TYPE** Peabody-Kennedy Mill. BURNER

DATE

INDICATOR CARDS

R. P. M.	PORT H. P.	PORT I. P.	PORT 2 I. P.	PORT L. P.	R. P. M.	STARBOARD H. P.	STARBOARD I. P.	STARBOARD 2 I. P.	STARBOARD L. P.
I. H. P.					I. H. P.				
% LOAD	TURBINE				% LOAD				
CUT OFF					CUT OFF				

REMARKS

PERSONNEL

ENGINEER	NAME	MECHANICAL ABILITY	DISCIPLINE	EFFICIENCY
CHIEF	C. J. Pierce	A	A	A
1st ASST.	C. McLean	A	A	A
2d ASST.	V. Perkins	A	A	A
3d ASST.	V. R. Whitehurst	A	A	A
4th ASST.				
MASTER	A. Anderson			

REMARKS

ENGINE DEP'T CREW	EQUIPMENT	OPERATION
A	B	A

A Excellent — A Very Good — +B Good — B Fair — -B Probation — C Poor — D Exceedingly Poor

REMARKS

Vessel taken over by Operators

FUEL SUMMARY

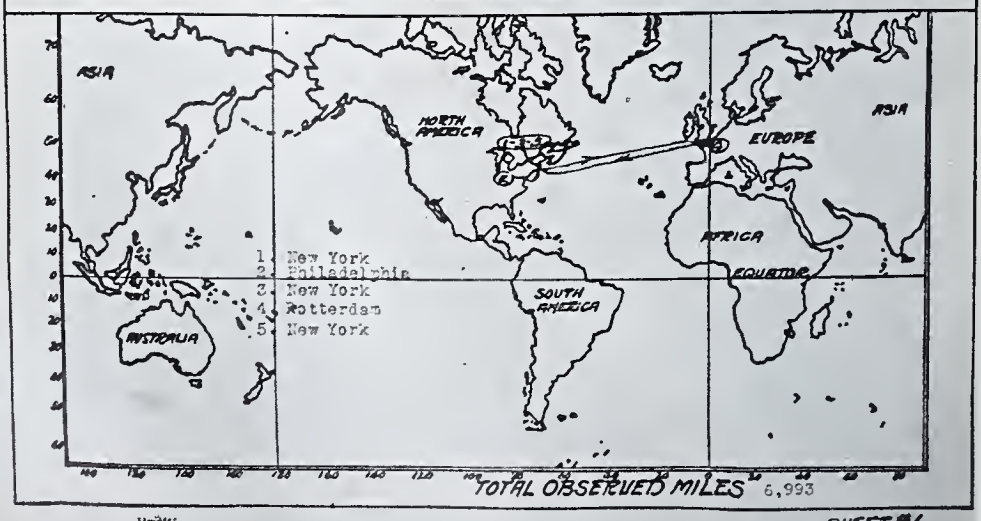
ON BOARD ARRIVING AT	4:01 PM - 11-16-27		
LAST VOYAGE No.	BBLS.	TONS	743
PURCHASED U. S. AT	Philadelphia		
THIS VOYAGE No. 57	BBLS.	TONS	721
PURCHASED ABROAD AT	Rotterdam		
THIS VOYAGE No. 57	BBLS.	TONS	296
FUEL ON BOARD ARRIV'G AT	New York		
THIS VOYAGE No. 57	BBLS.	TONS	321
FUEL CONSUMED			
THIS VOYAGE No. 57	BBLS.	TONS	1439

PRESENT PHYSICAL CONDITION

		MTE
ENGINE ROOM	Fair	B
MAIN ENGINES	Reported good; gears fairly good	-A
PUMPS	Inboard condensate - W. E. worn	-A
CONDENSERS	Main and aux. tight	A
DYNAMOS	Reported good	A
REFR'G MACHINERY	Good	A
BLOWERS	Primary being replaced	B
BOILER ROOMS	Floor plates require snugging up.	A*
BOILERS	Port-center minor leaks; all smoke-box doors	+B*
FURNACES	Good; stack requires 2 more courses	-A
BURNERS	Good	A
HEATERS, FUEL OIL	Tight and clean	A
HEATERS, FEED	Good	A
[illegible]	Rotors to be replaced	B
PLUMBING	Iron pipe and fittings - minor repairs	-A
HEATING	Good	A
LIGHTING	Minor repairs	-A
STEERING ENG.	Good - space O. K.	A
WINDLASS	Good	A
WINCHES	Minor repairs. No. 1 starboard	-A
HULL	Good condition	A
TANKS	Tight; reserve feed reported clean	A
DECK	Free rust	-A
CARGO HOLDS	Good	A
QUARTERS	Fairly good	+B
ROOMS	Good	A
DECK HOUSES	Free rust	-A

REMARKS *Warped; uptakes at base warped. Covering three boilers poor condition. Coal feeders to be repaired; coal taken in Rotterdam poor - M-3%; VM-26.5%; FC-55.8%; Ash-12.7%; S-2.4%; B.T.U.-12,430.

Bunkers checked; fuel oil checks - 2,400 Bbls. on arrival.



SHEET #1

Fig. 6. Report of Operating Data and Summary of Fuel Performance. S. S. Mercer

S. S. "MERCER" VOYAGE 57-1

PASSAGE	FROM		NEW YORK		PHILA.		NEW YORK		ROTTERDAM		SUMMARY							
	DATE		11-16-27		11-19-27		11-23-27		12-17-27		ALL							
	TO		PHILA.		NEW YORK		ROTTERDAM		NEW YORK		PASSAGES							
	DATE		11-17-27		11-20-27		12- 8-27		1- 2-28									
PASSAGE CONDITIONS			D. H. M.		D. H. M.		D. H. M.		D. H. M.		D. H. M.						D. H. M.	
1	DURATION PILOT STATION TO PILOT STATION		0- 15- 44		0- 11- 44		14- 7- 7		15- 18- 34		31- 5- 14							
2	OBSERVED DIST. MILES P.S.-P.S.		126		128		3375		3362		6993							
3	HOURS REDUCED SPEED		-		-		-		-		-							
4	HOURS STOP		-		-		-		-		-							
5	REASON RED. SPEED																	
	STOP																	
6	WEATHER CONDITIONS		MOD.		MOD.		4- Mod. 10- Rough		8 - Mod. 8- Rough		42%- Mod. 58%- Rough							
7	DRAFT LEAVING	FOR'D	8'6"	MEAN FOR PASSAGE	13'6"	MEAN FOR PASSAGE	24'5"	MEAN FOR PASSAGE	17'5"	MEAN FOR PASSAGE		MEAN FOR PASSAGE		MEAN FOR PASSAGE				
		AFT	15'6"		17'3"		27'0"		21'8"									
8	DRAFT ARRIVING	FOR'D	8'8"		11'11"		22'3"		14'9"									
		AFT	15'6" 12'1½"		15'1" 14'5"		26'4" 25'0"		18'5" 18'1"									
CARGO	9	DISPLACEMENT	TONS Δ															
	10	CARGO	TONS		None		375		6429		2598		9027					
	11	CARGO	TYPE		-		Gen.		Grain-Gen.		Gen.		Grain-Gen.					
PASS'GERS	12	HOTWELL PASSENGERS—	FIRST CLASS		186		144		133		142		-					
			SECOND CLASS		-		-		-		-		-					
		TOTAL REV.	THIRD CLASS		70,000		63,040		1,721,750		1,829,630		3,684,420					
BALLAST	13	BALLAST	TONS		None		None		None		600		600					
	14	BALLAST	TYPE		-		-		-		S.W.		S.W.					
SPEED	15	WHEEL KNOTS			9.82		11.84		11.06		10.65		10.84		Fuel oil used			
	16	OBSERVED SPEED KNOTS			8.14		10.91		9.83		8.89		9.33		at sea while			
	17	PER CENT SLIP			17.11		7.85		11.12		16.53		13.93		cleaning			
	18	AVERAGE R. P. M.			74.2		89.5		83.6		80.5		82.0		coal screens.			
OPERATING CONDITION	19	BOILER PRESSURE			200		200		210		208		-		2nd passage 10 Bbls.			
	20	H. P. CHEST PRESSURE			160		190		198		197		-		3d pass-100 Bbl			
	21	VACUUM	FROM		28.7"		28.5"		28.7"		28.7"		-		4th " - 90 Bbl			
	22	SUPERHEAT	F°		62		72		68		68		-		In port, oil			
	23	No. OF NOZZLES			9		10		9 1 10 5/12 6		9 2/10 5/12 9		-		used when ship			
	24	AVERAGE Ꞃ. H. P.			-		-		2583		2497		-		not on exhibi-			
	25	AUX. EXHAUST BACK PRESS.			15		15		10		10		-		tion or dock			
	26	SEA INJECTION	F°		54		54		57		53		-		trial.			
	27	OVERBOARD DISCHARGE	F°		70		70		70		67		-		Phila. - 60 Bbl			
	28	BOILER FEED	F°		240		240		220		220		-		N. Y. -120 "			
	29	STACK TEMP.	F°		480		500		520		520		-		Rott. - 210 "			
	30	FURNACE DRAFT	INS.		2.0		2.0		2.0		2.5		-					
OIL WATER	31	FRESH WATER 24 HRS.	TONS		30.5		28.65		16.5		15.5		16.5		Total fuel oil			
	32	FRESH WATER	TOTAL TONS		20		14		238		245		517		consumption,			
	33	LUBRICATING OIL 24 HRS.	GALS.		5 - 10		5 - 6		9 - 145		- - 145		19 - 306		610 Bbls.			
	34	CYLINDER OIL 24 HRS.	GALS.		- - -		- - -		- - 2		- - 2		- - 4					
FUEL PERFORMANCE	35	HRS. DOCK PILOT STA.	TO		0- 2- 9		0- 7- 22		0- 2- 33		0- 3- 10		0- 15- 14					
			FROM		0- 7- 6		0- 2- 59		0- 3- 48		0- 2- 33		0- 16- 26					
	36	FUEL CONS. DOCK P.S.	TO		3		13		5		9		31					
			FROM		13		5		9		6		33					
	37	FUEL CONS. AT SEA	TONS		24		21		595*		601		1241*					
			BBLS.		-		-		-		-		-					
	38	FUEL CONS. 24 HRS.	TONS		38.53		42.97		37.07		38.10		37.68					
			BBLS.		-		-		-		-		-					
	39	LBS. FUEL PER Ꞃ. H. P./HR.			-		-		1.34		1.42		-					
	40	LBS. FUEL PER MILE			420		367.5		351.7		400.3		376.7					
	41	MILES PER TON ACTUAL			5.33		6.10		6.37		5.60		5.95					
	42	MILES PER TON STANDARD			-		-		6.25		Excess slip		-					
	43	EFFICIENCY RATING			-		-		102.0		Wheel cutting water							
PORT OPERATION	44	PORT OF			NEW YORK		PHILA.		NEW YORK		ROTTERDAM		ALL PORTS					
	45	DURATION IN PORT			0- 1- 55		2- 3- 10		3- 1- 40		9- 4- 20		14- 11- 05					
	46	TOTAL PORT CONS.	TONS BBLS.		2		14		47		71		134					
	47	DAILY PORT CONS.	TONS BBLS.		DAILY PORT CONSUMPTION AFFECTED BY DEMONSTRATION RUNS.													
	48	NO. OF BOILERS IN PORT			1 - 2		1		1 - 2		1 - 2		1 - 2					
	49	NO. OF WINCHES USED IN PORT			-		-		-		-		-					
	50	WINCH HRS.			-		90		210		1056		1368					

*Includes 65 tons lost in bunker fire.

	VOYAGE EXPENSE	AMOUNT	COST
51	FUEL ABROAD	296 - T.	
52	WATER ABROAD	505 - T.	
53	STORES ABROAD		
54	REPAIRS ABROAD No. E D S	COST. $	
55	REPAIRS AT HOME No. E D S	COST. $	

SIGNED Chas. A. Fitzer Jan 3 1928
ENGINEER INSPECTOR FUEL CONSERVATION SECTION

SIGNED [illegible] 1/3/28
FUEL CONSERVATION SECT.

SC 20 AVERAGE PORT EFF. FOR VOYAGE 80.4% AVERAGE SEA EFF. FOR VOYAGE 102% E. B.

SHEET No. 2

FIG. 6

Fig. 6. Reverse of Report of Operating Data

The relative economic merit of pulverized fuel, as compared to liquid fuel, is subject to so many variables that it is impossible to state, without knowing definitely all of the characteristics, such as unit cost, heat value, etc., of each of the fuels under discussion for any particular application, just how much or how little would be gained by the substitution of the one fuel for the other.

As a means of making ready determination when the characteristics are known, a chart has been drawn up as shown on Figure 7. On this chart are a series of straight lines giving the heat content of the coal, which are crossed by a series of straight lines giving the heat content of the oil. Both of these sets are crossed by another series of straight lines designated as the efficiency ratio. The efficiency ratio is explained by the following equation:

$$\text{Efficiency ratio equals: } \frac{E_c\,(1 - A_c)}{E_o\,(1 - A_o)}$$

E_c = boiler efficiency, burning pulverized coal.
E_o = boiler efficiency, burning fuel oil.
A_c = percentage of total steam to pulverizer drive, etc.
A_o = percentage of total steam to fuel oil auxiliaries.

Coal costs allow for three men more in fireroom than when burning oil.

To use the chart, you enter it from the ordinate side, at the price which you must pay per barrel for fuel oil, carry it over to the efficiency ratio line, which has been determined, and thence from the point of intersection go in a vertical direction to the heat value of the oil under consideration. From this intersection carry over in a horizontal direction to the heat value of the coal under consideration and drop down to the abscissa where you will obtain the maximum price that can be paid for a ton of that particular coal to equal the results that will be obtained from the particular type of oil purchased at the price originally assumed.

On the chart is drawn an example, using 18,500 B.t.u. oil purchased at $1.00, with an efficiency ratio of 0.92 per cent, compared with 14,000 B.t.u. coal, which shows that $4.80 is the maximum that can be paid for this coal to equal the cost obtained with this oil.

At the present state of development of pulverized fuel for marine purposes, we find that 0.92 per cent represents approximately the efficiency ratio that is being obtained. There is no reason, however, by adoption of efficient driving units for pulverization or the useful

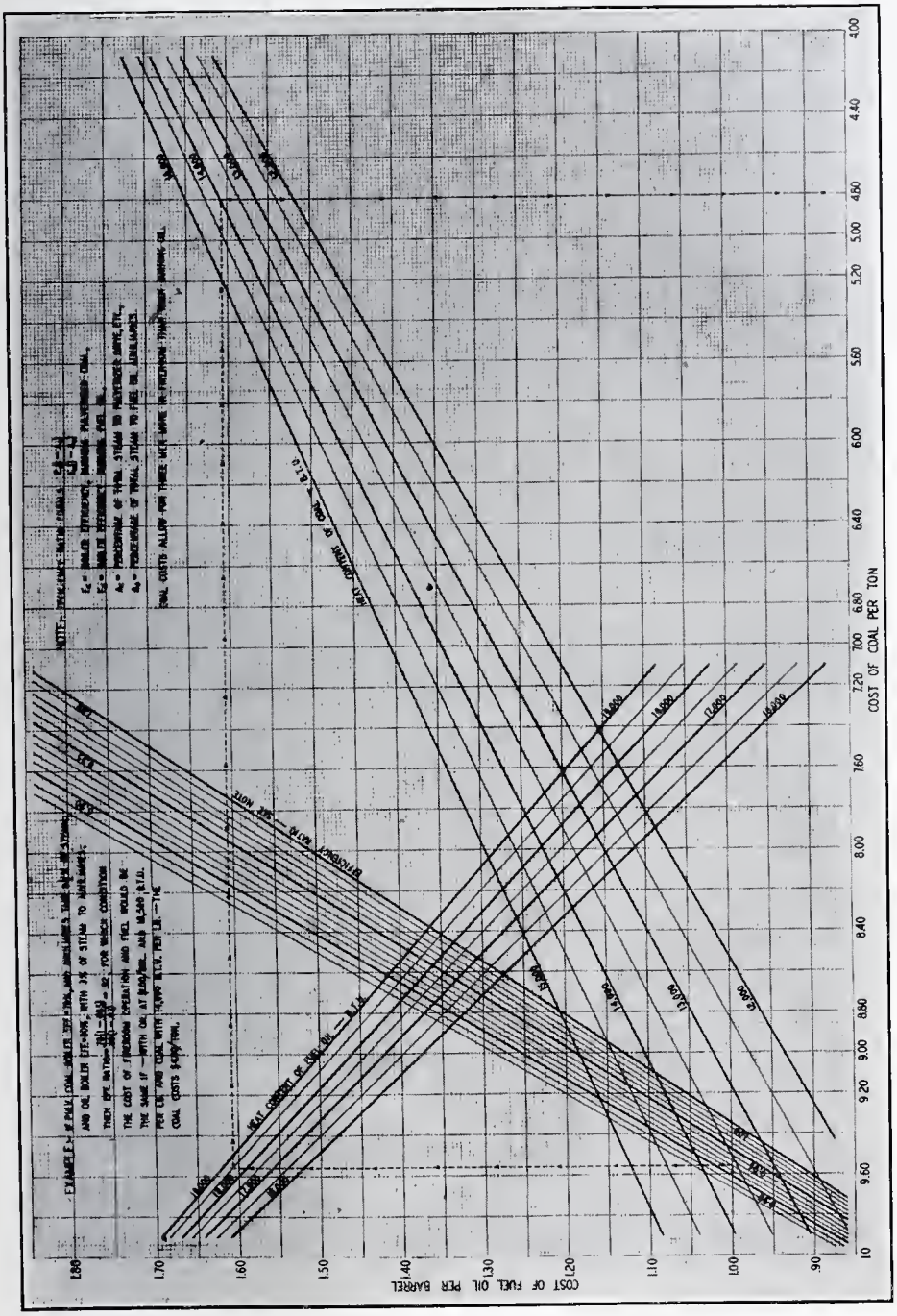


FIG. 7. MAXIMUM BUNKER PRICES OF COAL TO PERMIT EQUITABLE OPERATION OF A PULVERIZED COAL VESSEL AS COMPARED TO AN OIL BURNER FOR VARIOUS PRICES OF FUEL OIL

utilization of the exhaust steam from the pulverizing plant, why this efficiency ratio should not be brought up to 100 per cent, in which case the fuel cost would be raised to $5.20, or, in other words, the simple rule of comparison is that under present conditions pulverized fuel operating costs are equal to those of fuel oil when you can purchase 4.8 barrels of 18,500 B.t.u. oil for the price of one ton of 14,000 B.t.u. coal, but that it is entirely reasonable that this ratio be increased from 4.8 to 5.2.

The initial voyage of the S. S. *Mercer* was made with 14,000 B.t.u. coal costing $5.05 per ton. Applying this value to Figure 7, it will be noted that it would require $1.01 per barrel or less oil price for 18,500 B.t.u. oil to equal or better the fireroom operating cost of this voyage.

TABLE I

FIREROOM PERSONNEL FOR 3-BOILER CARGO VESSEL

	OIL	HAND-FIRED COAL	PULVERIZED FUEL
Number of firemen	3	9	3
Wage per man per month	$65.0	$67.5	$67.5
Number of coal passers	0	3	3
Wage per man per month	$0	$60.0	$60.0

Subsistence per man per day = $.60.

The S. S. *Mercer* herself has never been operated as a hand-fired coal burner, hence comparison cannot be made with her own past performance in this respect, albeit at the time she was making her first voyage with pulverized fuel, five sister vessels were operating in the same trade using hand-fired coal and steaming with three boilers burning run-of-mine coal while the *Mercer* was using only two boilers and burning slack coal. The average performance of these five vessels for their voyages made concurrently with that of the *Mercer* shows 9.55 knots speed with 12.14 per cent slip and a fuel consumption of 414 pounds coal per mile.

In making an economic analysis between pulverized fuel, hand-fired coal and liquid fuel, consideration must be given to the fireroom personnel charges. These have been incorporated on chart of Figure 7, and are given in Table I.

S. S. "MERCER"—GRADES OF FUEL

As part of the experimental work on the S. S. *Mercer*, various grades of coal have been bunkered.

Table II gives the analysis of the eight types of coal used up to date, all of which have been successfully used. It will be noted that these coals cover a range of 16.6 to 30.35 per cent volatile content, 12,800 to 14,610 B.t.u. content, and 6.3 to 13 per cent ash content.

TABLE II

GRADES OF FUEL: BUNKERED BY S. S. MERCER

Analysis on dry basis

	A	B	C	D	E	F	G	H
Volatile.....	16.6	18.8	20	20.4	22.8	29.5	29.5	30.35
Fixed carbon.....	73.2	70.8	73.7	72.8	69.45	57.5	62.2	62.55
Ash.....	10.2	10.4	6.3	6.8	7.75	13.0	8.3	7.10
Sulphur.....	2.14	1.0	1.4	1.5	1.2	2.4	1.75	1.6
British thermal units.....	14,000	13,250	14,570	14,610	14,440	12,800	14,250	14,425
Ash fusion..			2,510		2,690	2,350		
Size.....	100% Slack	100% Slack	75% Slack	75% Slack	Run of mine	Run of mine	100% Slack	Run of mine

DEDUCTIONS FROM S. S. "MERCER'S" OPERATION

The year's operating service of the S. S. *Mercer* has brought out several salient points that must be observed in effecting a satisfactory installation of pulverized fuel in Scotch marine boilers, which may be summarized as follows:

a. Considerably finer pulverization of fuel is required than that necessary with large refractory lined furnaces such as found in shore plants.

b. High turbulence of flame is required to produce complete and rapid combustion necessary in the comparatively short flame travel characteristic of a Scotch boiler.

c. Consistently uniform distribution of pulverized fuel between various furnaces of Scotch boiler is necessary to maintain efficient performance.

d. The power plant incident to producing pulverized fuel must

be of an economical type, which may be secured either by installation of efficient low water rate units or by useful employment of exhaust, if less efficient units be used.

e. Extra precaution must be taken to secure dust-tight smoke-box doors and uptakes; otherwise, when using soot blowers it will be impossible to maintain a satisfactory fireroom condition.

f. The velocities of coal stream throughout cycle requires special consideration to prevent overloading of fans and coal precipitation in pipe lines and to secure satisfactory selection of superfine grind from mill and turbulence at burner.

g. Personnel must be trained to give the same close supervision to "velocity" as is required in regard to viscosity and pressures when using fuel oil.

h. The usual fireroom instruments, such as orsat and pyrometer, are important but of greater importance are the draft gauge and smoke indicator.

i. Sized coal or 100 per cent slack gives more uniform operating conditions than will run-of-mine; in fact, bunkering with run-of-mine will require use of crushers to produce fuel having a limited maximum size; otherwise, feed to mill will be very irregular, a condition that will be reflected throughout the whole operation of boiler plant.

The reliability and safety features of pulverized coal have been thoroughly demonstrated by the past year's sea service on the S. S. *Mercer.* It has been further demonstrated by about six months' service on the S. S. *Lingan,* a Canadian Collier operated by the Dominion Coal Company, Ltd., in its trade between Nova Scotia and St. Lawrence River ports, which vessel has an installation very similar to that of the S. S. *Mercer.* The S. S. *Stuartstar,* operating between England and Buenos Aires for the Blue Star Company, has likewise proven this point by a 13,000-mile voyage using pulverized fuel on one of her boilers. The S. S. *Stuartstar* installation is an experimental one using Clarke-Chapman high speed mills and Woodeson's burners. The original experiment has been extended by installation of equipment on a second boiler which is a double-ended Scotch boiler, this being the first adaptation of pulverized fuel to a double-ended Scotch boiler.

The ability to use satisfactorily fuels which could not be used otherwise in a Scotch marine boiler has likewise been definitely demonstrated.

The economic possibilities have been indicated and the problem in

relation to adapting pulverized fuel to marine practice has been crystallized.

Real definite progress has been accomplished. However, the final standard type of installation still needs to be worked out.

Conversions and new installations now being made will further the development of the art and aid towards transforming it from an art into a fixed science having definite laws that can be employed with confidence by marine engineers.

DEVELOPMENT WORK CARRIED ON DURING THE PAST YEAR AT THE PHILADELPHIA NAVY YARD FUEL OIL TEST PLANT

While the S. S. *Mercer* was creating and sometimes solving new problems in connection with marine use of pulverized fuel at sea, the shore test plant at the Philadelphia Navy Yard has been working out the solution to the problems and furthering the development work by testing out new equipment.

DISTRIBUTION

One of the most difficult problems encountered in the firing of a three-furnace boiler with pulverized coal similar to the ones on the *Mercer* and at the Fuel Oil Testing Plant has been proper distribution and a vast amount of time has been devoted to the solution of this problem at the Testing Plant. It is a comparatively simple matter to convert one stream of coal and air into two equal streams but when an attempt is made to subdivide into three equal streams it becomes a real problem. This is largely due to the fact that the mixture of air and coal passing through the single pipe is not homogeneous throughout the length of the pipe nor across its section and the non-uniformity varies with changes in air and coal rates and also along the length of the pipe.

More than twenty types of distributors have been tried out at the Test Plant. Of these, a pneumatic type has proven to date to be the most satisfactory for universal service and it has been installed on the S. S. *Mercer* in lieu of the original mechanical type.

THE BLO-GUN

Early in the operation of the S. S. *Mercer* it became apparent that serious consideration must be given to the erosion by pulverized fuel on the primary air fan as the effect of fan blade erosion extends

beyond the fan itself, inasmuch as the erosion is not uniform and an unbalanced high speed fan quickly sets up vibrations which may prove disastrous to the fan drive.

There are several methods of attacking the problem, as, for example:

a. Use of forced draft instead of induced draft for air sweeping mill. This method is now employed by several pulverizer manufacturers and is fairly satisfactory. However, it has a tendency to create turbulence in the mill which militates somewhat against classification of superfines by air current.

b. Use of special materials for manufacture of fan blades: Considerable experimental work has been conducted along this line, which has resulted in varying success under different conditions. Up to date, ordinary soft iron has, however, given the best universal service.

c. Use of comparatively cheap and easily renewed rotor: A number of shore plants have adopted this compromise method but it cannot be accepted as satisfactory as it interferes with continuous operation such as must be maintained by the seagoing installation.

d. A fourth method is to apply the ejector principle, which has been attempted at the Test Plant by the use of the so-called Blo-Gun.

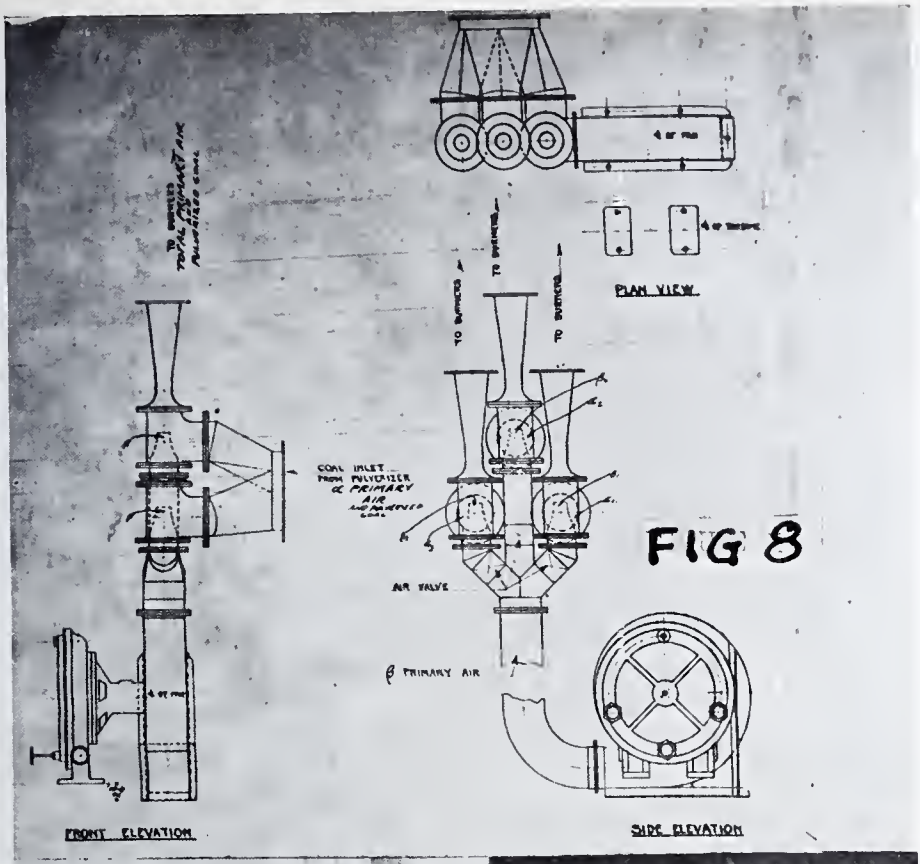
In attacking the problem of fan erosion, the engineers of the B. T. Sturtevant Company were called into consultation and the Blo-Gun, as finally evolved, is the result of their coöperative effort.

The original idea was to have a single ejector nozzle operating on outlet of mill and discharging to a distributor head. It was decided, however, to attempt to not only work out fan erosion but also distribution with the same device.

The Blo-Gun as finally built is shown by Figures 8 and 9, the former being a line drawing of the set-up while the latter is a photograph of the actual Blo-Gun.

The principle of the device is to create a partial vacuum by means of a high velocity air current discharging from a nozzle across an enlarged chamber into a venturi throat. The partial vacuum sets up an air current which sweeps through the pulverizer, picking up the finely pulverized fuel and carrying it into the mixing chamber, where it joins with the stream of injection air and forms the total primary air and coal mixture going to the burner.

The injection air or fan discharge is the carrier air which is known as the β air. The induced air from the mill which sweeps out the



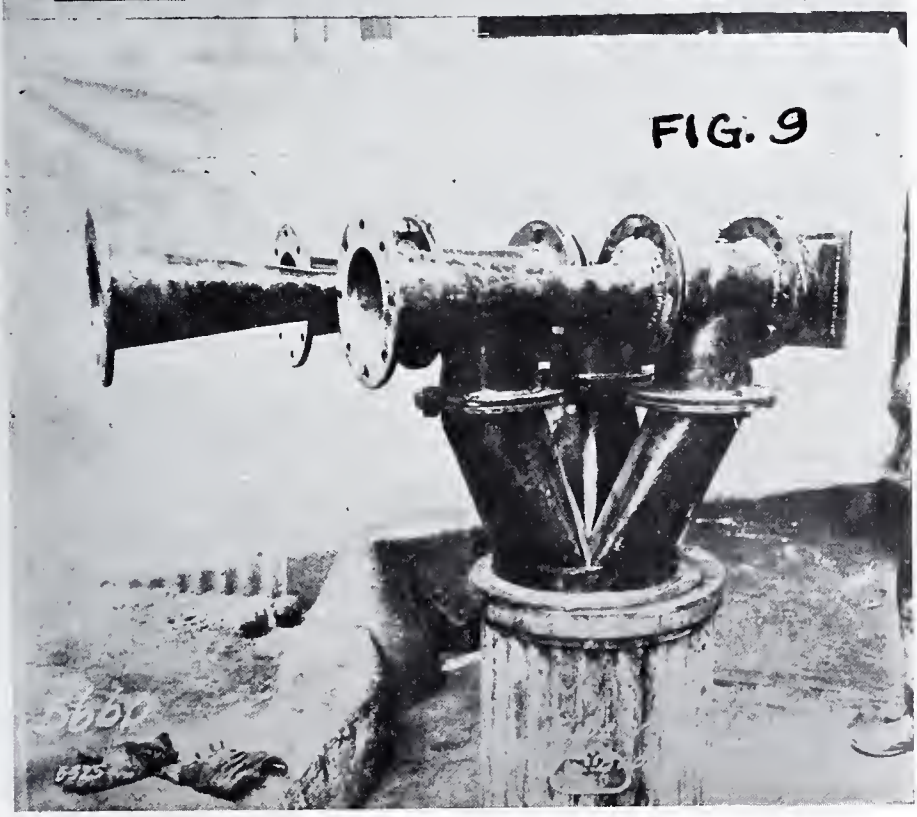


Fig. 8. Drawing of Blo-Gun Set-up

Fig. 9. Photograph of Blo-Gun

pulverized fuel is known as the α air. The combination of α and β air is the primary air of combustion.

The device must be set up close to mill discharge as long leads will either create so great a friction that the β air cannot create sufficient vacuum to maintain an induced air circuit or else in order to overcome friction the pipe areas will be so large that sufficient velocity will not be maintained to keep the coal in suspension.

Furthermore, the β air, which is of approximately the same proportion to the total primary air as is the carrier air usually induced between mill and primary air fan, precludes the admission of additional carrier air such as would be required if connections be removed from close proximity to mill discharge, as additional air would produce too lean a mixture for satisfactory combustion.

Service tests with Blo-Gun direct connected to mill have not yet been conducted but quantitative values of α and β air have been determined by measuring the flow from fan and the induced air by means of orifices. The results of these trials were shown in Figures 10 and 11.

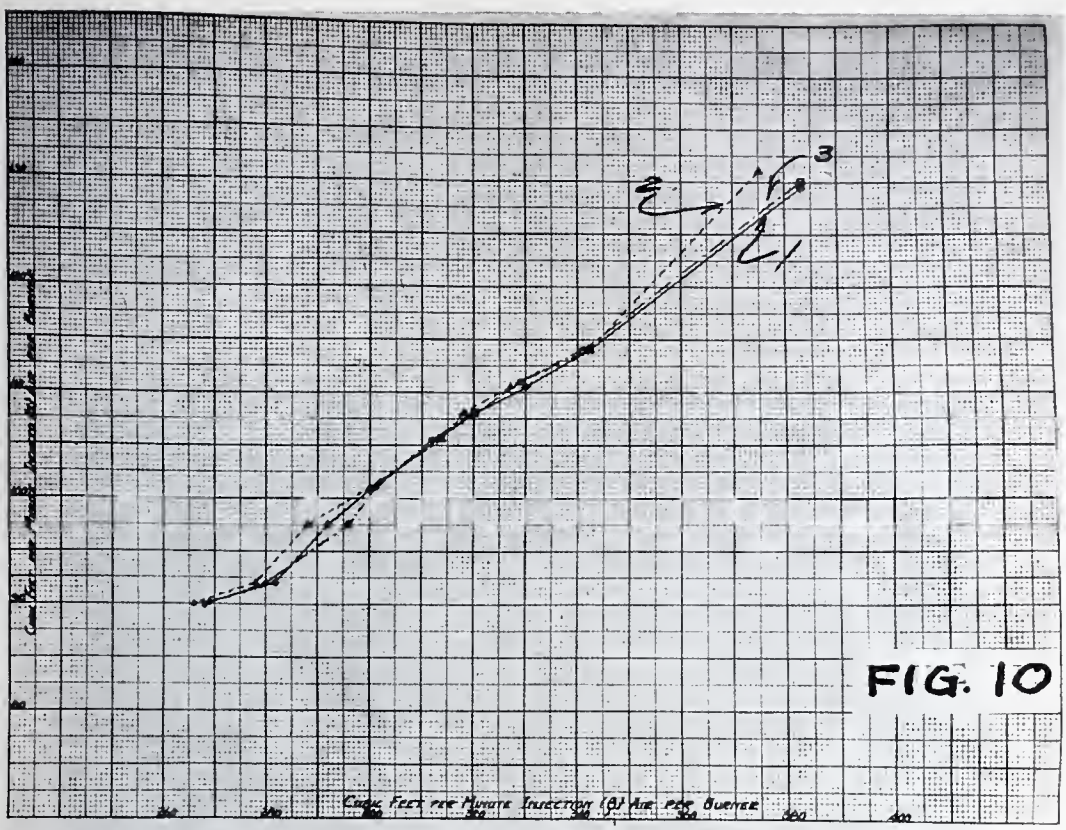
Figure 10 shows a series of three graphs giving the α air quantities for each of the three mill connections plotted against the β quantities. During these trials no air valves were installed in β connections. The need of such valves for proper distribution is shown by the variation at the higher rates.

Figure 11 gives total volume of α obtained for various β rates.

The Blo-Gun requires service tests to determine its real merit. It has been included in this record, however, as it is a new method of attacking one of the serious problems characteristic of pulverized fuel.

BONNOT MILL—LODI BURNER

During the tests of various distributors and the Blo-Gun at the Fuel Oil Testing Plant, Lodi burners and a Fuller-Bonnot slow speed ball mill were in use. The burner installation is shown in Figure 12. Provision is made for swinging out the burners for the purpose of getting to the furnaces and doors for slag removal are provided at the bottom. The mill is equipped with internal and external classifier or separator. The external classifier returns for regrinding any coarse particles of coal which may have passed through the mill. Operation of this equipment soon showed it to be satisfactory for use with Scotch marine boilers and though only short runs were



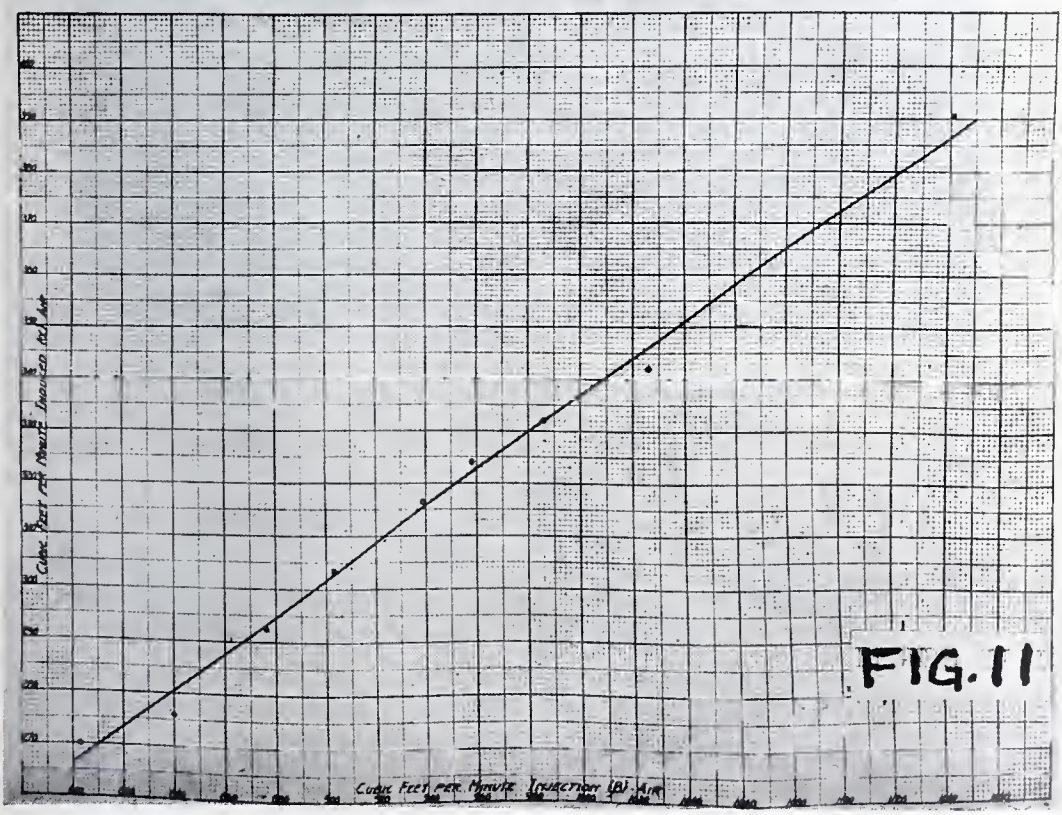


Fig. 10. Graphs Giving the Alpha Air Quantities for All of the Three Mill Connections Plotted against the Beta Quantities

Fig. 11. Total Volume of Alpha Obtained for Various Beta Rates

made, the evaporative efficiencies were highly gratifying. The character of grind produced by the mill is excellent, over 80 per cent passing through a 300 mesh sieve. The tests on this apparatus are not yet completed but have been temporarily postponed through the courtesy of the Fuller-Lehigh Company in order that an entirely new type of installation might be tested out.

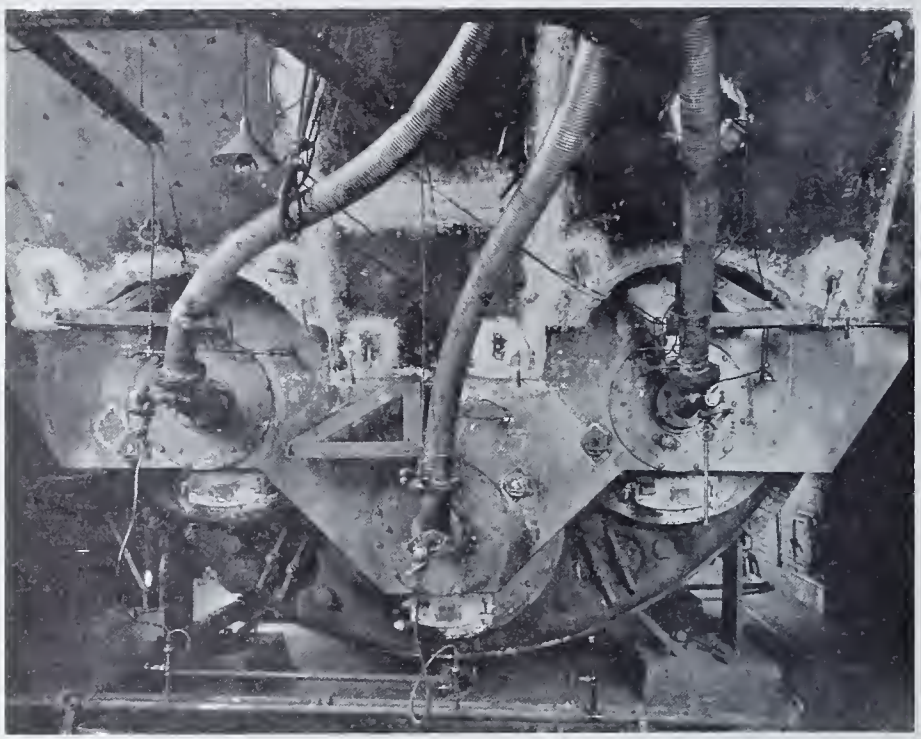


FIG. 12. LODI BURNER INSTALLATION

TODD COMBINED BURNER AND PULVERIZER

This is an installation which provides a complete pulverizer, burner and fan with their driving unit for each furnace.

The Todd Dry Dock and Engineering Corporation, who produced this new system, have carried on considerable development work using a small two-furnace Scotch boiler at their Tebo's Yacht Basin. They did, however, desire to apply the equipment to a full-sized boiler, where a complete test could be made, and as the system has several characteristics which make it desirable for sea service, arrangements were made for its installation at the Test Plant.

The operation of feeding, grinding and furnishing the necessary

primary air of combustion are comprised in one unit which also embodies the coal burner, air register and a fuel oil atomizer as an auxiliary. The unit is very compact in design as will be seen from an inspection of Figure 13, which shows an installation for three furnaces as installed on the test boiler at the Fuel Oil Testing Plant.

This equipment is now under test at the Fuel Oil Testing Plant and while no completed data have been obtained as to its operation, preliminary results have been very satisfactory. All three units

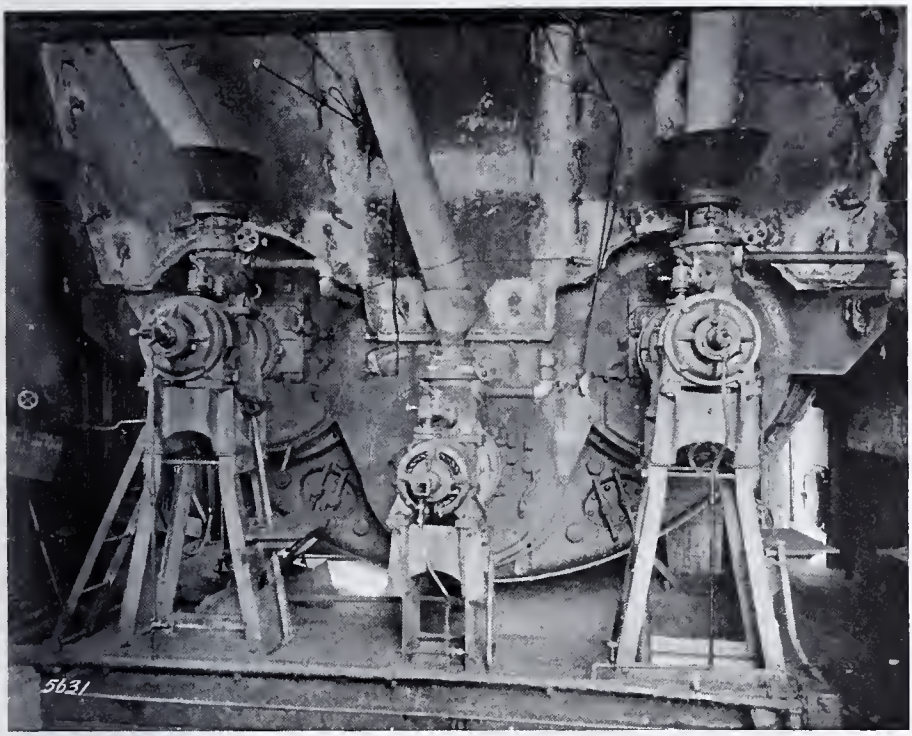


FIG. 13. TODD COMBINED BURNER AND PULVERIZER INSTALLATION FOR THREE FURNACES

have been in successful operation at the same time and although some difficulties have arisen, these are being worked out and indications are that the equipment will be successful. Very complete combustion is possible at rates from 200 pounds to over 600 pounds per unit per hour, with little or no smoke and high CO_2.

PROGRESS OF DEVELOPMENT

The progressive development in the adoption of pulverized fuel to Scotch marine boilers is shown on Figure 14. This figure gives a

series of four boiler efficiency curves plotted against the equivalent evaporation per square foot of heating surface. Each of these curves is representative of results that were obtained during the various stages of development. They are not the results of any particular series of tests run during the various stages but rather are average results obtained during the period.

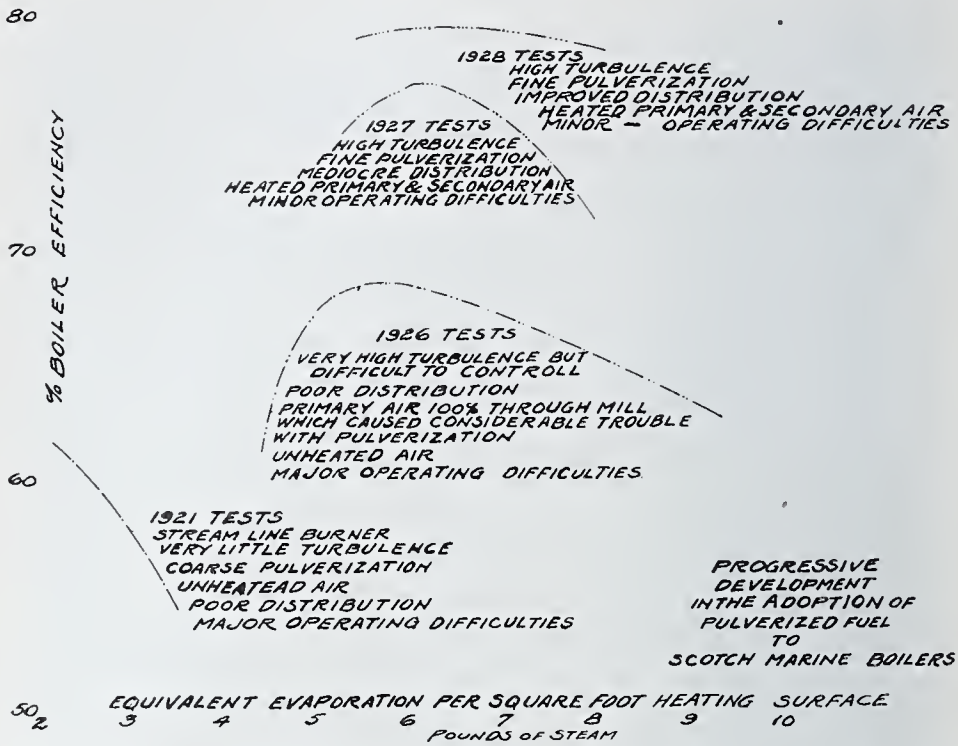


FIG. 14. PROGRESSIVE DEVELOPMENT IN THE ADAPTION OF PULVERIZED FUEL TO SCOTCH MARINE BOILERS

It will be noted that the 1921 curve covers but a limited range of evaporation at the lower rates and falls off very rapidly as the rate of evaporation is increased.

Figure 16 is a photograph of one of the furnaces taken at the end of 48 hours' steaming during the 1921 tests. Comparison is invited between the appearance of the furnace at that time and the appearance at the end of the 240-hour test made in 1927 as shown by Figure 15.

The results obtained in these initial tests were so discouraging that the whole problem of adoption of pulverized fuel for marine use lay dormant until 1926.

Fig. 15. Photograph of a Furnace at End of 48 Hours Steaming Test During 1921

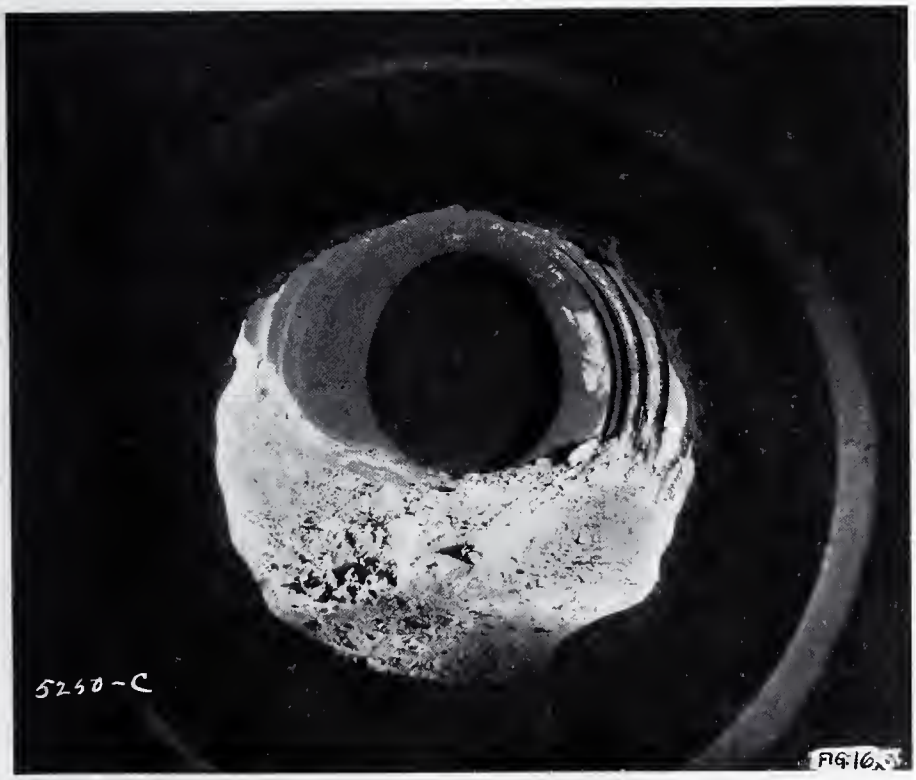


Fig. 16. Photograph of Furnace at End of 240 Hours Test in 1927

In 1926 it was decided to make use of the information that had been gained in shore plant operation, in reference to the effect of flame turbulence and fine pulverization, and a second series of tests were run. These were purely of an experimental nature. The equipment installed, as has been previously stated, was by no means suitable for seagoing service, as may be noted from the complexity of piping shown in Figure 2.

The tests did prove, however, that high rate of evaporation could be obtained when using pulverized fuel in a Scotch boiler and, in general, the series of tests showed such a marked improvement over the results of 1921 that it was desirable to continue the development work in order to secure a practical installation that could be used on shipboard.

The 1927 series of tests were run with this purpose in mind, the range of rate of evaporation being limited to that which would be necessary on shipboard. The control of turbulence and pulverization, also improvement in distribution and the utilization of heated primary and secondary air produced a marked increase in efficiency. In fact, the results were satisfactory enough to warrant a seagoing installation using the same equipment as was employed for this series, which is shown by Figure 3.

The 1928 tests have been run chiefly for the purpose of correcting operating difficulties that had been encountered on the seagoing installation.

The ultimate peak of development has not yet been realized but it will be seen from Figure 14 that there has been a very considerable improvement since the early tests of 1921.

CONCLUSION

The possibility of efficient, reliable and safe operation of marine boilers with pulverized fuel is no longer a hypothesis. It is an established fact demonstrated by actual operation both under test plant and sea service conditions.

The impression that pulverized fuel has entirely passed out of the experimental stage, however, must be avoided, for such is not the case.

For some of the marine trade routes pulverized fuel can in its present state of development be adopted with every assurance of satisfactory results but in others the application must still be considered an experiment.

Service tests of the various available low grade bunker fuels are required to determine their economic merits.

The program at the Test Plant calls for tests of several mills and burners other than those that have been employed to date in addition to further tests on some of the equipment mentioned in this paper.

The principles governing the selection of equipment to be used in the future tests are:

a. Simplicity of construction and operation, which is generally accompanied by reduced first cost;

b. Low power consumption, in order that improved boiler efficiency be not offset by increased auxiliary load.

c. Reduced floor space, so that equipment can be installed without making structural modifications.

There are certain basic facts regarding pulverized fuel which should be determined, the establishment of which can best be handled by a research rather than a development program. The main items that require such treatment are:

a. The pulverized fuel carrying capacity of air under varying temperatures, humidity and velocity conditions for the varying degrees of fineness of the fuel;

b. The establishment of a standard method of determining "grindability" of various fuels.

c. A survey of the various bunker fuels of the world to determine their grindability.

The determination of these basic facts is of such vital importance to the development of the art that the research program should be sponsored by all the allied interests connected with the production, preparation and consumption of solid fuels. These include fuel producers, distributors, manufacturers of equipment, shipowners and operators.

Much of the pioneer work has been accomplished by the Government. It now devolves upon the private interests to carry on.

This paper undoubtedly has a decidedly marine flavor, which is natural since it outlines the development of pulverized fuel for seagoing use. However, there is no reason whatsoever why the lessons which have been learned should not be put to useful service in other fields. The thought has occurred that the problems of the marine engineer are similar to those of the man in the small power plant who must make the equipment he has available perform at its highest efficiency. He usually has small boilers; he cannot install

new ones specially designed to meet his conditions; he has trouble getting good firemen and keeping them—in short, they both have much the same difficulties. This also applies in a certain degree to the combustion problem of our railroads. Therefore, the successful application of pulverized fuel to marine boilers affects the coal industry in general to a far greater extent than would be evidenced by the movement of bunker coal at our seaports.

CHARACTERISTICS AND CLASSIFICATION OF FUELS IN THE UNION OF SOCIALIST SOVIET REPUBLICS

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1. The Fuel-Study in the Union of Socialist Soviet Republics

The present paper is the result of fourteen years study of Russian fuels by the author, this work having been given a powerful impetus and vast possibilities after the opening of the Thermo-Technical Institute in Moscow. From its very establishment the Thermo-Technical Institute has continuously carried on systematic work on the study of Russian fuels. The three following lines of approach by way of collecting materials are being used for the purpose: (1) the collection of results of analyses at official acceptance stations of railways and State industrial enterprises, at mines and oil fields; (2) the results of analyses carried out by the Chemical Laboratory of the Thermo-Technical Institute proper on behalf of industry, and also at numerous furnace and boiler tests at the boilers laboratory of the Institute and at industrial plants; (3) the results of a purely scientific investigation of Russian fuels as carried on in the Thermo-Technical Institute and in some other research institutions, viz., data on the distillation of coals, on the extraction action of solvents upon coals, their microscopic structure, extensive results of investigation of the inorganic matter of fuels, etc.

On the basis of results obtained we are at present able: (1) to obtain fully reliable data which, far from characterizing only casual fuel samples, may be considered as true average technical analyses of fuels now consumed in the Union of Socialist Soviet Republics; (2) to carry on a really systematic and exhaustive study of the properties of Russian fuels based on scientific research work.

The systematization of all accumulated material is, as already mentioned, continuously carried on by the Thermo-Technical Institute, by whose endeavors more than 20,000 analyses have been collected during several years (including here 4,000 technical analyses made by the Chemical Laboratory of the Institute). The systematization of data regarding the properties of Russian fuels not only covers separate coal fields but also individual mines and sometimes

where conditions permit is even extended to coal seams, so that the Thermo-Technical Institute will soon be able to issue the first Russian catalogue of fuels.

2. Standardization of Fuel Quality

This standardization was begun before the war, as the first specifications for the supply of Donetz fuels to railways were introduced as early as in 1909. These specifications were based on a classification of coals as to their caking power and contents of volatile matter. The quality of coal was rated only after the contents of ash and sulphur. Later on, specifications were more than once changed.

At present, specifications for coal acceptance are in use for all principal regions of Russia. Similar specifications exist also for oil.

The specifications which are still in use may be summarized as follows:

Fuel Oil. Fuel oil or Mazout is subdivided into 4 categories, differing only in regard to pouring point. The pouring point of the first class "A" should not be above −10°C., while a range of solidifying from +24°C. to +35°C. is permitted for the last class "Г." All other characteristics are equally standardized for all 4 classes, viz., the lowest flash point should not be lower than 60°C. (50°C. for Grozni), maximum contents of mineral admixtures −1 per cent, alkali −0.1 per cent, and moisture −0 per cent, while the maximum viscosity should not exceed 7° Engler.

The above specification (with no consideration to moisture) is given to the consumer as a standard so that he might reject such fuels that would not be up to standard quality.

At the same time a determinate allowance off oil prices is made for surplus mineral admixtures (0.5 to 1 per cent) and also for all the water present.

Coals. Coals are classified only for the Donetz Basin which is noted for the variety of its coals. As to other coal fields—the character of coal is already defined by the name of the particular coal field on account of the similarity of main characteristics. Two main characteristic features underlie the classification of Donetz Basin coals: (1) characteristics of coke determining the caking power of coal; (2) contents of volatile matter in coal as this may be seen from Table I.

Non-caking coals and anthracites are subdivided into grades depending on the size of lumps. The grades shown in Table II are now adopted for home consumption of Donetz anthracites:

For other non-caking or open burning coals namely the Kizel, Tcheliabinsk, Southern Kuznetzk, Tcheremhovsk and Donetzk long flame screenings—the minimum size of lump is standardized. For the latter types of coal and also for Donetzk anthracites there is a fixed amount of culm, above which a reduction off sale price is

TABLE I

NUMBER	KIND OF COAL	MARK	CONTENTS OF VOLATILE MATTER IN MOISTURE AND ASH FREE COAL V^c IN PER CENT	CHARACTERISTICS OF COKE
1	Dry long-flame coal	Д	More than 44	Non caked, pulverulent or slightly fritted
2	Gas coal	Г	36–47	Caked, melted, sometimes porous (swollen)
3	Steam fat coal (bituminous coal)	ПЖ	25–36	Caked, melted, compact or moderately compact
4	Coking coal	К	20–36	Caked, melted, compact or moderately compact
5	Steam caking coal	ПС	Less than 20	Caked or melted from compact to moderately compact
6	Lean coal	Т	Less than 20	Non caked, pulverulent or slightly fritted

TABLE II

	MARK	SIZE OF LUMPS IN INCHES
Lump	АП	More than 5
Large nut	АК	5 to 1
Small nut	АМ	1 to $\frac{1}{2}$
Rice no. 1	АС	$\frac{1}{2}$ to $\frac{1}{4}$
Rice no. 2	$АС_2$	$\frac{1}{4}$ to $\frac{1}{8}$
Culm	АШ	$\frac{1}{4}$ to 0
Rune of mine (without lump)	АРШ	5 to 0

allowed. Donetz coals are also tested for mechanical strength for the purpose of minimizing losses during transportation and from incomplete combustion.

The specifications for coals fixes the limit amount of moisture. If this limit is exceeded, a discount off sale price is again allowed. Prohibitive contents of sulphur and ash are also considered. The

TAI

MAIN CHARACTERISTIC

NUMBER	KIND OF FUEL, REGION, AN) ORIGIN AND GRADE OF FUEL	MARK	SIZE OF LUMP	APPARENT		COM		
				V^b	C^b	H^b	N^b	O
			mm.					
	FIREWOOD:							
1	Firewood (coniferous)			84	51.0	6.2	0.6	
2	Firewood (foliate)			86	50.0	6.15	0.6	
3	Firewood (mixed)			85	50.5	6.2	0.6	
4	AVERAGE PEAT CENTRAL-INDUSTRIAL REGION			70	58.8	6.0	2.0	
	BROWN COAL:							
	Sub-Moscow:							
5	Lump	К	>50	45	70.7	5.3	1.4	
6	Nut	О	50–20	45	68.2	4.8	1.4	
7	Fines and pea	МС	20–0	45	68.4	4.9	1.4	
8	Run of mine (without lump)	РМ	50–0	45	68.3	4.8	1.4	
	Ural:							
9	Tcheliabinsk			44	72.9	4.9	2.0	
10	Bogoslovsk			42	67.5	4.2	1.5	
	Eastern Siberia:							
11	Tchernov			47		5.3		
12	Kivda			40		4.3		
13	Ziboonny			48		5.7		
14	Tavrichan			49		5.6		
	COAL:							
	Donetz Basin:							
15	Dry long-flame coal	Д		45	77.0	5.4	1.8	
16	Gas coal	Г		39.5	81.0	5.5	1.6	
17	Steam fat coal	ПЖ		30.5	85.5	5.2	1.6	
18	Coking coal	К		23	87.0	4.9	1.6	
19	Steam caking coal	ПС		16.5	89.0	4.5	1.6	
20	Lean coal	Т		12.5	91.0	4.1	1.5	
	ANTHRACITES:							
	Donetz Basin:							
21	Lump	АП	>125	4	94.5	1.85	0.7	
22	Large nut	АК	125–25	4	94.5	1.85	0.7	
23	Small nut	АМ	25–13	4	94.3	1.85	0.7	
24	Rice	АС	13–6	4	94.3	1.85	0.7	
25	Culm	АШ	6–0	5.5	93.0	2.0	0.8	
26	Run of mine (without lump)	АРШ	125–0	4	94.0	1.9	0.7	
	Ural:							
27	Iegorshin			9	92.5	3.5	0.6*	
28	Poltava			3	96.0	1.1	0.5*	
29	Bredinsk			3.5	93.4	1.5	0.7	
	COAL:							
	Ural:							
30	Kisel			41	78.5	5.2	0.7	
31	Lunievsk			42	76.6	5.5	0.9	
	Caucasus:							
32	Tkvibooli			42	78.8	5.0	1.6	

II

RUSSIAN FUELS FOR 1927

E MATTER			DRY FUEL	FUEL "AS FIRED"			W^h	SOFTENING TEMPERATURE	CHARACTERISTICS OF COKE	WEATHERING	SPONTANEOUS COMBUSTION
S_v^b	Q_g^b	Q_n^b	A^d	W^f	Q_g^f	Q_n^f					
								°C.			
0	4,880	4,555	1.0	30	3,380	2,980	8	—	Separate	Nil	Nil
0	4,740	4,420	1.0	30	3,285	2,885	8	—	compact		
0	4,840	4,515	1.0	30	3,355	2,950	8	—	lumps		
0.2	5,650	5,335	9.0	30	3,600	3,220	11	1,160			
3.8	6,830	6,550	20.0	32	3,715	3,380	7	1,250	O	Very	Very
7.0	6,540	6,290	27.5	31	3,270	2,965	7	1,250	O	strong	easy
5.5	6,540	6,280	31.0	32	3,070	2,760	7	1,250	O		
6.5	6,540	6,290	31.0	33	3,025	2,715	7	1,250	O		
1.2	6,920	6,660	15	17	4,880	4,600	10	1,150	O	Slight	Nil
0.6	6,020	5,800	14.2	26	3,820	3,530	17	1,110	O	Strong	Nil
0.7	7,000*	6,720	8.5	33	4,290	3,930	17		O		
0.3	7,000	6,775	12.5	25	4,595	4,300	10.5		O		
0.8	7,190	6,890	12	26.5	4,650	4,300	11		O		
0.3	7,500*	7,205	16.5	13	5,450	5,160	9.5		O		
5.0	7,730	7,445	14	11	5,915	5,635	5	1,150	I	Strong	
4.0	8,080	7,790	12.5	5	6,715	6,445	3	1,110	II	Considerable	
3.0	8,440	8,165	13	4	7,050	6,795	1.3	1,160	III–IV	Slight	
3.0	8,540	8,280	13.5	3	7,165	6,930	1.0	—	IV	Slight	
2.5	8,580	8,345	11	3	7,405	7,185	0.7	1,110	IV	Slight	
1.2	8,560	8,345	7.5	3.5	7,640	7,430	0.5	1,140	V	Nil	
1.6	8,160	8,065	4.5	5	7,405	7,285	1	1,180	O	Nil	Nil
1.6	8,160	8,065	6	5	7,285	7,170	1	1,180	O		
1.8	8,140	8,045	10.5	5	6,920	6,810	1	1,180	O		
1.8	8,140	8,045	14.5	6	6,540	6,430	1	1,180	O		
1.5	8,020	7,915	18	8.5	6,015	5,890	1	1,180	O		
1.5	8,140	8,040	13.5	6	6,620	6,500	1	1,180	O		
0.6	8,450	8,625	18*	5*	6,585	6,410	1	>1,400			
0.4	8,060	8,000	19	8*	6,005	5,915	1*				
0.8	7,950	7,870	15	8*	6,215	6,110	1*				
7.0	8,000	7,725	23	5	5,850	5,620	1	1,300	I–III	Quite	Nil
7.8	7,970	7,680	33	5	5,075	4,860	1		I–III	slight	
1.3	7,660	7,395	16.5	9	5,820	5,565	5	>1,400	I–II	Considerable	

TABLE

NUMBER	KIND OF FUEL, REGION, AND ORIGIN AND GRADE OF FUEL	MARK	SIZE OF LUMP	APPARENT		COM		
				V^b	C^b	H^b	N^b	O
	COAL:		*mm.*					
	Fergana:							
33	Soolewkta			36	76.0	4.0	1.0	
34	Kizil Kiya			36	76.0	4.0	1.0	
	Kuznetzk Basin:							
35	Anjera Sudjensk.			16.5	90.2	4.3	1.5*	
36	Lenin (Koltchugin)			41	82.0	5.6	2.4	
37	Kemerovo			28	86.2	4.9	1.8*	
38	Prokopjevo and Kiseliovo			21	87.1	4.0	2.1	
	Minusinsk:							
39	Tchernogorsk			41		5.3		
	Irkutsk:							
40	Tcheremhovsk			47	78.0	5.8	1.5	
	Soochan:							
41	Fat coals			25		5.1		
	OIL SHALES:							
42	*Veimarn*	$(CO_2)^b = 20.6$		80	75.0	9.0	0.3	
43	*Kashpeer*	$(CO_2)^b = 21.9$*		80	69.8	9.0	2.0	
44	*Undor*	$(CO_2)^b = 17.2$		70	66.5	8.0	2.0	
	COKE:							
	Donetz:							
45	Metallurgical	KM		4*	95.6	0.7	1.3	
46	Foundry	KJI		4*	96.4	0.7	1.4	
	CHARCOAL:							
47	Dump charcoal			11*	91*	2*	7*	
48	Oven charcoal				80*	4*	16*	
49	MAZOUT ($\gamma_{15} = 0.900 - 0.906$)				86.65	12.7	0.5	

Notes: Figures with the asterisk mark * are merely presumptive, being taken on the ground of a small number of a ses or according to estimate.

Softening temperature indicates mean softening point in semireducing atmosphere and is only a rough proxi average of ash fusibility varying in both directions within a wide range with regard to individual mines and seams.

Apparent laboratory ash content a^d is given in all cases, wherefore combustible matter is not a true but only a ventional value and contains not true amount of oxygen, but $O_c^b - R_c^b$, where R_c^b is in algebraic increase of ash w (positive or negative) when heated in crucible.

Coke as regards external characteristics, is respectively classed after Gruner.

When refiguring Q_n^b the magnitude 5.85 (9H+w) was subtracted.

specifications are based on the calorific value of absolutely dry coal determined in a bomb calorimeter. The normal limits of calorific value are determined for every grade and coal field, the stock price being raised when these limits are exceeded and vice versa an allowance is made when these normal limits are not reached.

—*Continued*

E MATTER			DRY FUEL	FUEL "AS FIRED"			W^h	SOFTENING TEMPERATURE	CHARACTERISTICS OF COKE	WEATHERING	SPONTANEOUS COMBUSTION
S_v^b	Q_g^b	Q_n^b	A^d	W^f	Q_g^f	Q_n^f		°C.			
2.0	6,950	6,740	16.5	18	4,760	4,510	11		I	Quite	Strong
2.0	6,950	6,740	9.5	26	4,655	4,360	11		I	slight	
0.7	8,600	8,375	9.5	5	7,395	7,170	1	1,300*	IУ–У		
0.7	8,150	7,855	9.5	9	6,710	6,415	2.5*	1,120	II–III		
0.8	8,380	8,120	11.5	8.5	6,785	6,525	2.5	1,120	IУ–III		
0.5	8,100	7,890	12	7	6,630	6,415	3	>1,300	I–(II)		
0.5	7,850	7,570	6	11.5	6,530	6,230	7.5		II	Nil.	
1.1	7,750	7,445	14.5	9.5	5,995	5,705	5	1,160	II–I		
0.5	8,600	8,330	15	4	7,020	6,775	1.2		II–III		
2.0	6,440[2] / 8,100	6,065[2] / 7,625	45+11.3[1]	25[3]	2,655	2,355	2.5	1,160	O	Nil	Nil
4.8	6,670 / —	6,555 / —	59+9[1]	18[3]	2,240	2,005		1,080	O		
4.5*	5,850 / 7,100	5,500 / 6,680	61+6.7[1]	25[3]	1,710	1,470	3*	1,040*	O		
1.9	7,980	7,945	13	7.5	6,420	6,350	0.8		O	Nil	Nil
1.0	8,000	7,965	11.5	7	6,585	6,510	0,8		O		
0*	7,800*	7,695*	2.0*	9	6,955	6,810				Nil	Nil
0*	7,300*	7,090*	2.0*	10	6,440	6,195					
0.15	10,760	10,090	0.1	2*	10,535	9,870	—	—	—	Nil	Nil

[1] The first item stands for apparent laboratory ash, while the second represents all carbonic acids emitted in the disintegration of carbonates.

[2] Top figures are given with estimate for apparent combustible matter obtained after subtraction of moisture and laboratory ash only, i.e., combustible matter including also carbonic acid resulting from the disintegration of carbonates; bottom figures refer to combustible matter with correction for carbonic acid obtained after subtraction of laboratory ash moisture and the carbonic acid of carbonates, but without correction for the action of hydrates, pyrite-sulphur etc.

[3] Natural moisture in seam is indicated; market moisture amounts to about 15 per cent for all the three kinds of oil shales.

3. Main Characteristics of Russian Fuels

From the standpoint of combustion the basic characteristics of fuel are as follows:

w^h—hygroscopic moisture of fuel, characteristic from the viewpoint of fuel classification and important because it concerns drying preliminary to grinding.

w^f—moisture of fuel when fired

A^d—ash contents of absolutely dry fuel.

It is obvious that ash contents should be estimated only for absolutely dry fuel so as to eliminate the influence of variable moisture, which, with many fuels, may fluctuate within a very wide range thereby causing instability of ash contents in fuel when fired.

Since all technical analyses give only apparent ash contents, viz., that directly obtained in laboratory by means of burning in a crucible, we refer to this particular figure *only*, i.e., laboratory ash contents. When scientifically determining the true ash contents it is essential to introduce the value R—correction for changes in the weight of ash subject to presence of pyrite-sulphur, carbonates, hydrates, etc.

Further, the ultimate analysis of fuel would be most efficiently reckoned from the organic matter, i.e., from fuel deprived of moisture, ash and sulphur. Owing however to the fact that most technical analyses make no distinction between combustible and non-combustible sulphur, it appears more practical to give the ultimate analysis with regard to combustible matter, i.e., dry and ashless fuel. In this instance again it is not the true figure of combustible matter that is estimated but only the apparent one. For obtaining the true figure of combustible matter we should introduce the correction value "R" for ash and accordingly also for fuel oxygen, which is usually obtained from the difference.

When the characteristics of combustible matter are known, it is of course easy to recalculate them for any given amounts of moisture and ash.

Caking power is one of the most essential characteristics of coal. This determines all losses due to the combustible falling through the grate and being carried away in flue dust. Readiness of spontaneous combustion and weathering qualities and also the softening temperature of ash are, likewise, among the fundamental furnace characteristics of fuels.

A summary is to be found in enclosed table embracing all fundamental kinds of Russian fuels of industrial value at the present time.

We must say that the table is far from characterizing all existing Russian deposits, but deals only with those that are being worked at present and whose output tends to become more or less considerable. The figures contained in the table, viz., moisture and ash contents are typical for marketed industrial fuels. They were determined by the many thousands of analysis referred to above.

The ash contents of coals in seams for most fuels should of course be estimated much lower.

Further, the very composition of combustible matter also represents a certain average for the fuels of a given coal field or class; of course, in reality, more or less considerable deviations are always to be found.

We have naturally introduced the necessary subdivisions in cases of those fields whose different portions produce fuels of varying description.

But there again we had in view only the characteristics of existing market fuels and not at all the coal deposits proper.

Wood Fuel. Since this particular kind of fuel is of especial importance under Russian conditions we have, of late, made a series of complete analyses of wood-fuel, so that the composition of the latter is characterized by more than 100 complete analyses and may therefore be said to be altogether reliable. For Russian timber the calorific value of combustible matter taken from coniferous trees is about 150 calories per kilogram or 3 per cent higher than that taken from foliate trees.

Peat. The Central Industrial Region of Russia supplies the predominant amount of peat generally produced. Ukrainian and partly also Ural peats give much higher ash contents: A^d = 15 to 20 per cent. Similary, for Russian peats the percentage of carbon in combustible matter (ash and moisture free fuel) generally varies within the range 52 to 64 per cent depending on the age of the given peat. The predominant number of peats produced in the Central Industrial Region have however a composition closely approaching that indicated in our table. The age of peat also determines the contents of volatile matter.

Brown Coals. Under Russian conditions brown coals are of secondary importance. Of all fields exploited at present, only the brown coals of the Sub-Moscow, Bogoslovsk and Tcheliabinsk regions have any industrial value. Some Siberian mines are also exploited at present, namely those of Tchernovsk, Kivda, Zyboonny and Tavrichansk. The rather numerous remaining seams of brown coals in Russia have either not been worked at all, or have been abandoned, or still have an altogether insignificant output used for local consumption only.

Coals. Coals are adequately represented by all existing coal fields and types assuming any industrial importance at the present time.

The leading place is taken by the Donetz Basin, covering about 77 per cent of the output, next comes the Kuznetzk Basin with about 8 per cent and at last, the Kiselovsk and Sub-Moscow Basins with 3 per cent each, so that the said four regions give as much as 91 per cent of the total coal output of the Union of Socialist Soviet Republics. The secondary importance of the remaining regions is evident from this.

As may be seen from the table only the Sub-Moscow brown coals and Kizel-Lunievsk coals possess high ash contents, while ash contents average 11 to 12 per cent for the remaining coals and brown coals.

Relatively low softening temperatures of ash are likewise typical for some grades of Russian coal. The table shows them to be within the range of 1,000° to 1,200°C., only in some cases falling to 900°C. and seldom rising above 1,300°C. It should be mentioned here that these figures have been taken from the researches of Engineer N. G. Pazukov, Chief, Chemical Laboratory of Thermo-Technical Institute. This property of Russian coals somewhat impedes the process of their combustion.

Anthracites are at present nearly exclusively obtained from the Donetz Basin. There is an insignificant production of anthracite also in the Jegorshin and Poltavo-Bredinsk regions in the Ural.

Oil Shales. These are represented in the table by 3 deposits: the Veimarn seam near Leningrad and the Undorsk and Kashpoorsk seams in the region of Sizran and Oolianovsk (Middle Volga). A small working of oil shales now takes place only in the Veimarn district.

Since oil shales contain a large amount of carbonates their ash content in the table is given as the sum of two figures of which the first stands for apparent laboratory ash, obtained as residue after burning in a crucible and the second stands for carbonic acid resulting from the disintegration of carbonates, so that the sum shows the true ash contents (without correction for hydrates, pyrites, etc.). Accordingly, the calorific values of combustible matter are shown both for apparent combustible (obtained through subtraction of moisture and laboratory ash) and for true combustible matter obtained after subtraction of moisture and true ash.

Oil shales assume hardly any industrial value at present.

Bogheads and Sapropelites. These are now hardly worked at all. A small number of bogheads is only produced in conjunction with the

brown coals of the Sub-Moscow Basin. A large number of bogheads and sapropelites, rich in volatile matter and tars, is to be found in numerous but small Siberian fields of which the Matagan, Olonkon, Khaharei, Barhat, Kasianovsk and Priangarsk should be mentioned.

Mazouts. In connection with the work on combustion of mazouts with high paraffin contents the Thermo-Technical Institute has in the last years completed a number (more than 90) of analyses of Russian mazouts, different mazouts with pouring point up to +40°C. having been investigated. Our researches proved the elementary composition of all four grades of Russian mazout remains constant, in accordance with the composition shown in the table, as the specific gravities of all 4 grades fluctuate within a very small range namely only 0.900 to 0.906 on the average. The average contents of floridine tars was also found to be very close for all 4 grades, averaging about 11 per cent. The paraffin contents of paraffinless mazout, grade "A," with pouring point below −10°C. was about 1.6 per cent increasing up to 10.5 per cent for paraffin mazout (grade "Г") with average pour point +35°C.

At a temperature of 50°C. the average viscosities of mazouts were likewise found to be very close to one another fluctuating about 4° Engler, easily solidified paraffin mazouts having at temperatures somewhat above 35°C. even a lower viscosity than paraffinless mazouts (viscosity, being ascertained mainly through the availability of tars) and rising to 20° to 30° Engler and still higher with tarry mazouts. The specific gravity of mazout increased, the hydrogen contents and calorific value of combustible matter are necessarily reduced.

COMPARATIVE EFFICIENCY OF BURNING TYPICAL KINDS OF FUEL

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I. Some General Considerations Underlying the Comparative Valuation of Boiler Furnaces and Fuels

In order to present this problem in generalized form and so as to summarize in so far as possible the main characteristics of individual furnace designs and kinds of fuel, let us first establish a general method for a comparative valuation of different furnaces, which method will be applied in the subsequent treatment of the subject.

A mere comparison of overall efficiency of existing installations could certainly not be considered an adequate method for ascertaining the efficiency of various furnaces and fuels. For it is clear that the over-all efficiency depends not only on the performance of the furnace, but also on the work of heating surfaces and the development of their sizes, or, to make this point more lucid, we may put it that the efficiency besides the furnace and fuel factor hinges also to a great extent on the temperature of flue gases T and that of air t, i.e., on the difference $T-t$. As to this difference, the dependence of the latter may be mainly traced to the rate of evaporation per unit boiler heating surface, and also to the availability, and, provided there be such, to the size of economizer and air preheater. Thus, in order to eliminate the factor of heating surfaces acting upon the results of furnace work, it would seem preferable to refigure to the always constant though conventional magnitude $T-t$, which we, in what follows, shall assume equal to 150°C., or 175°C. for gases leaving the installation, fitted with economizer, in accordance with the usual temperatures of flue gases, and an air temperature of about 25°C. This done, it will appear obvious that the efficiency of a given furnace installation will be fully determined by the following three factors:

1. The coefficient of air excess in furnace, α_f; but since it is difficult to determine this magnitude experimentally, the coefficient of air excess behind the boiler α_e is usually substituted. This latter value is, however, greater than α_f the difference amounting to the air leakage at the boiler walls. Now, for a given furnace and fuel

the coefficient of air excess α_1 is determined by the furnace rate of heat liberation which latter value had better be characterized by two magnitudes: $\frac{Q}{R}$ = rate of heat liberation per unit grate area or per combustion surface, the respective units being thousands of calories per square meter per hour and $\frac{Q}{V}$ = rate of heat liberation per unit furnace volume where the units are thousands of calories per cubic meter per hour.

2. Waste through chemical incompleteness of combustion, q_3, if flue gases contain products of incomplete combustion such as carbon monoxide, hydrogen, methane, heavy hydrocarbons, etc. This value will chiefly be the function of $\frac{Q}{V}$ and α.

3. Losses through mechanical incompleteness of combustion, q_4. These consist of waste through fuel dropping between grate-bars (siftings), q_s, loss of combustible in ash and clinker, q_A, and loss through waste with flue dust, q_c. Losses through mechanical incompleteness of combustion, $q_4 = q_s + q_A + q_c$, also depend on the rate of combustion, i.e., $\frac{Q}{R}$ and $\frac{Q}{V}$ and on the excess of air.

Thus, the main three magnitudes determining furnace efficiency are connected both with the rate of combustion and also mutually with one another.

Having ascertained the conventional temperature values for flue gases and air, i.e. T−t, we may express the influence of air excess, α_e, by the value of a respective heat loss; viz., given perfect combustion and steam blast lacking, the loss with flue gases for every fuel will be expressed by the following general equation:

$$q_2 = \left(\frac{a}{RO_2} + b\right) \cdot (T - t) \text{ per cent}$$

where $RO_2 = CO_2 + SO_2$

$$\left.\begin{aligned} a &= \frac{C^f + 0.368\, S_v^f}{0.54} \cdot c_d \cdot \frac{100}{Q_n^f} \\ b &= \left(\frac{9\, H^f + w^f}{100} + W_a^f\right) \cdot c_s \cdot \frac{100}{Q_n^f} \end{aligned}\right\} \qquad 1)$$

So that the values a and b remain constant for the given kind of fuel. However, since the coefficient of air excess α may be expressed by the equation:

$$\alpha = \frac{x}{RO_2} + y$$

where x and y are constant for the given class of fuel, namely:

$$x = \frac{1660}{79 + 100\,\beta}$$

$$y = \frac{21\,\beta}{79 + 100\,\beta}$$

where:

$$\beta = 2.38\,\frac{H - \frac{O^f}{8}}{C^f + 0.368\,S^f_v} + 0.005^*$$

* The values C^f, S^f_v, H^f, O^f, W^f, W^f_a give the respective percentages of carbon, combustible sulphur, hydrogen, oxygen and moisture in fuel as fired, while W^f_a stands for moisture brought in by air in kilograms per 1 kilogram fuel; Q^f_n stands for net calorific value of fuel as fired; c_d and c_s stand for corresponding mean specific heat of dry gases and vapor between T° and t° C.

we may write that

$$q_2 = [m\,(\alpha - y) + n]\,(T - t)$$

where m, n and y are again constants for a given class of fuel.

Thus, with given fuel, i.e., with known values of m, n and y, and a chosen constant difference T−t, the loss with flue gases q_2 will be reduced to the function of the coefficient of air excess α; consequently α being known, we may easily determine $(q_2)_{150}$ now reduced to the temperature difference T−t = 150°, so that:

$$(q_2)_{150} = 150\,[m\,(\alpha - y) + n]$$

where

$$m = \frac{C^f + 0.368\,S^f_v}{0.54 \cdot x} \cdot \frac{100}{Q^f_n} \cdot 0.323$$

$$n = \left(\frac{9\,H^f + w^f}{100} + w^f_a\right)\frac{100}{Q^f_n} \cdot 0.47$$

In case there be chemical and mechanical incompleteness of combustion, the formula becomes somewhat more intricate: however with given fuel and known q_3 and q_4 the value $(q_2)_{150}$ in this case, just the same, remains the function of air excess.

Namely having $q_3 = 0$ we obtain

$$(q_2)_{150} = 150 \left\{ \left[m\,(\alpha - y) + (9\,H^f + 100\,w_a^f) \cdot \frac{0.47}{Q_n^f} \right] \frac{100 - q_4}{100} + \frac{0.47\,w^f}{Q_n^f} \right\}$$

or

$$(q_2)_{150} = 150 \left[\frac{m\,(\alpha - y) + k}{100} (100 - q_4) + l \right]$$

where m, y, k and l are constants for a given kind of fuel respectively equaling

$$k = (9\,H^f + 100\,w_a^f)\,\frac{0.47}{Q_n^f}$$

$$l = \frac{0.47 \cdot w^f}{Q_n^f}$$

Further, bearing in mind that the amount of air theoretically required for the combustion of all not excessively moist fuels will be expressed by

$$L_o \cong 1.42\,\frac{Q_n^f}{1000}\ \text{kg/kg.}$$

and assuming the quantity of water vapors in air to be d grams per kilogram dry air, we have

$$w_a^f = 1.42\,\frac{Q_n^f}{1000} \cdot \alpha \cdot \frac{d}{1000}$$

Then, with d = 8 and after some simple transforming we ultimately have

$$(q_2)_{159} = \left[\frac{8970}{Q^f} \cdot \frac{K^f}{x}\,(\alpha - y) + \frac{635\,H^f}{Q_n^f} + 0.08\,\alpha \right] \frac{100 - q_4}{100} + \frac{70\,w^f}{Q_n^f}$$

where

$$K^f = c^f + 0.368\,S_v^f$$

Consequently, we may describe the sum total of furnace losses as the sum of $(q_2)_{150} + q_3 + q_4$, while the relative efficiency of the furnace (provided we neglect the very small losses due to radiation, which moreover can hardly be traced by even the most scrupulous experiments), will equal:

$$\eta_f = 100 - (q_2)_{150} - q_3 - q_4.$$

Thus, if we reduce all calculations to the constant difference $T-t$, ample possibilities are afforded for comparing furnaces and fuels of most varying description as the value η_f will always be the comparative gauge of such efficiency.

Moreover if this value is known, no particular difficulties will be encountered in ascertaining the relative over-all efficiency of any installation that would be fitted with a given furnace; we have only to subtract one more loss q_5—namely the radiation loss which for purposes of greater ease in comparison we shall in the present instance assume as being equal to 2 per cent; then, evidently, the comparative over-all efficiency of the installation will be read as follows:

$$\eta_{150} = 100 - (q_2)_{150} - q_3 - q_4 - q_5 = \eta_f - 2 \text{ per cent.}$$

It will be noted that in this formula no account has been taken of increased excess air gathering towards the end of the installation, viz., the value of additional air leakage through boiler setting is here neglected. Should we desire to obtain the actual figure for the given installation we may easily make the necessary reckoning on the ground of the above formulae, since, both the difference $T-t$ and the value $\Delta\alpha = \alpha_e - \alpha_1$ standing for air leakage along the way from the boiler to the end of the installation, are known.

The above method affords convenient means for comparing boiler furnaces and fuels of most varying description.

When computing the efficiency value we have, as is customary in the Union of Socialist Soviet Republics, in all cases been making use of net calorific value instead of gross. This appears much more representative for the comparison of individual furnaces, since heat losses due to the evaporation of moisture from fuel should by no means be attributed to furnace performance, since they are solely to be accounted for by the given kind of fuel; hence, should we reckon after gross calorific value, our valuation of furnaces would be considerably distorted, as the respective comparative efficiencies would appear lowered on account of the moist fuels being made use of.

II. TECHNICAL EFFICIENCY OF THE COMBUSTION OF TYPICAL FUELS

During the last few years the State Research Thermo-Technical Institute, has carried out a vast number of experiments on the combustion of different types of Russian fuels. The experiments were conducted at the Institute's own experimental station as well as at various industrial enterprises of the Union of Socialist Soviet Republics. Owing to the extensive experimental results thus accumulated we are now in a position to formulate some summarized conclusions regarding the efficiency of different typical kinds of fuel. In this paper we shall confine the subject to the discussion of mechanical stokers and those fed on pulverized fuel, leaving hand-fired furnaces out of the scope of the report.

TABLE I

CHARACTERISTICS OF TYPICAL FUELS

	V^b	A^d	w^f	Q_g^f	Q_n^f
Wood-fuel	85	1.0	35	3,120	2,700
Peat	70	9	30	3,600	3,220
Low-in-ash run-of-mine brown coal	55	5	30	4,590	4,200
Rich-in-ash slack brown coal (Sub-Moscow)	45	31.5	33	3,000	2,690
Dry long-flame coals	45	14	11	5,910	5,630
Caking coal	30	8	4	7,450	7,180
Low volatile coal	12.5	7.5	3.5	7,640	7,430
Screened anthracites (>3 mm.)	4.5	14.5	6	6,540	6,430
Anthracite Culm	4.5	20	9	5,840	5,710
Mazout	—	0.1	2	10,540	9,870

The overwhelming majority of all tests was carried out on chain-grates, since most kinds of industrial fuel in the Union of Socialist Soviet Republics belong to the non-caking category which affords very efficient combustion on chain-grates. In regard to caking fuels, it is inferred in the hereunder treatment that normal American underfeed stokers are used; the latter, however, having as yet no appreciable application in the Union of Socialist Soviet Republics, it was found necessary with a view to obtaining requisite data, to apply to the experimental results of American plants which had either been published in the literature or collected by the author during his stay in America in 1927.

In order to render the discussion as illustrative and brief as pos-

TABLE II

Comparative Technical Economy of Mechanical and Unit Powdered Fuel Furnaces. Without Driers, for Typical Fuels

Fuel			Firewood (chips)	Peat		Brown coals				Bituminous coals						Anthracites				Mazout	
						Run-of-mine, low-in-ash		Fines, rich-in-ash		Dry long-flame		Caking		Lean coals		Screened		Culm			
			Mechanical	Powdered	Mechanical	Powdered	Mechanical	Powdered	Mechanical	Powdered	Mechanical	Powdered	Mechanical	Powdered	Mechanical	Powdered	Mechanical	Powdered	Mechanical	Steam jet atomizer	Mechanical
Normal heat liberation per unit great area	Q/Rt	cal/m²h	900		1,600		900		900		1,000		200		750		900		750	—	—
Normal heat liberation per combustion chamber	Q/Vt	cal/m³h	290		350		280		250		300		350		350		400		350	300	350
Coefficient of air excess behind boiler			1.4	1.3	1.35	1.3	1.5	1.3	1.7	1.3	1.4	1.3	1.35	1.35	1.4	1.35	1.4	1.35	2.0	1.25	1.25
Heat losses:																					
With flue gases (at T − t = 150°C.)	$(q_2)150$	per cent	9.2	8.4	8.7	7.9	8.8	8.5	10.3	7.4	7.5	7.2	7.5	7.4	6.8	7.2	7.0	7.3	7.8	7.3	7.2
Due to chemical incompleteness of combustion	q_3	per cent	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.0	0.5	1.0	0.5	0.5	0.5
In siftings	q_4^S	per cent	0.5	—	0.2	—	0.5	—	1.0	—	1.0	—	0.2	—	1.5	—	1.0	—	5.0	—	—
In clinker	q_4^A	per cent		—	1.0	—	0.8	—	2.8	—	2.1	—	1.3	—	6.0	—	5.9	—	19.0	—	—
With flue dust	q_4^C	per cent	1.5	—	0.5	—	2.0	—	4.0	—	4.0	—	2.5	—	6.0	—	2.4	—	6,0	—	—
Sum total of mechanical losses	q_4	per cent	2	1.0	1.7	1.5	3.3	3.0	7.8	1.5	7.1	1.5	4.0	2.5	18.5	4.0	9.3	4.0	30.0	0	0
Comparative gross efficiency of furnace after Q_n^f	η_{fn}^g	per cent	88.3	90.1	89.1	90.1	87.4	88.0	81.4	90.6	84.9	90.8	88.0	89.6	79.2	87.8	83.2	87.7	61.7	92.2	92.3
Comparative gross efficiency of furnace after Q_g^f	η_{fg}^g	per cent	76.4	80.6	79.6	82.3	79.9	78.9	73.0	86.4	80.8	87.7	84.9	87.2	77.0	86.4	81.8	85.8	60.3	86.3	86.4
Energy consumption per ton fuel burnt	N/B	kwh/tn	2.0	20.0	2.2	20.0	2.9	21.0	2.3	21.0	3.5	15.0	4.0	15.0	4.1	22.0	3.7	20.0	4.4	—	—
Percentage of self consumption of furnace to the quantity of fuel burnt		per cent	0.2	1.9	0.2	1.5	0.2	2.4	0.3	1.2	0.2	0.7	0.2	0.6	0.2	1.1	0.2	1.1	0.2	2.3	0.3
Limit residuum of powder on screen No. 200			—	40	—	40	—	40	—	35	—	35	—	25	—	15	—	15	—	—	—
Comparative net efficiency of furnace after Q_n^f	η_{fn}^n		88.1	88.2	88.9	88.6	87.2	85.6	81.1	89.4	84.7	90.1	87.8	89.0	79.0	86.7	83.6	86.6	61.5	89.9	92.0
Comparative net efficiency of furnace after Q_g^f	η_{fg}^n		76.3		79.4		79.7		72.7		80.6		84.7		76.8		81.6		60.1	84.1	86.1
Over expenditure of fuel for mechanical stoker, gross		per cent			1.2		3.2		8.3		6.9		3.3		13.5		5.7		43.5		
Over expenditure of fuel for mechanical stoker net		per cent			−0.8		1.6		5.7		5.7		2.7		13.0		4.6		42.2	—	

sible, we do not propose to enter into the details of individual experiments on different kinds of fuel, merely stating the summarized data obtained for some typical fuels, for which purpose we have selected: (1) wood fuel, (2) peat, (3) low-in-ash run-of-mine brown coal of the Middle-German type, (4) fines of brown coal with high ash content represented by the slack grades of the Sub-Moscow brown coal, (5) dry long-flame coals, (6) caking coals, (7) lean coals, (8) sorted anthracite screened through no less than a 3 mm. mesh, (9) anthracite culm (falling through 6 mm. mesh), (10) mazout.

The fundamental characteristics of the above fuels are to be found in Table I in which are given the chemical analyses of the fuels forming the basis of all subsequent calculations.

The main results on the efficiency of the typical kinds of fuel are summed up in Table II. Each particular kind (except wood fuel) bear reference to respective data on combustion both in mechanical stokers and in pulverized form (assuming the unit system, without drier). The data for each kind of fuel represent average experimental results, excepting the few cases in which the lacking data are supplied by estimation.

In view of the novelty of the combustion of firewood on chain-grates, we deem it advisable to introduce some remarks respecting this method of wood fuel combustion.

Despite the high efficiency of shaft furnaces, the latter fail to raise the available rate of evaporation to any value approaching 40 kilograms per square meter per hour. Besides, they still require a large staff for attending to the boiler house, hauling wood and charging the furnace. Such furnaces also call for availability of firewood of uniform length, while the combustion of wood refuse assuming a varying and irregular form (such as branches, slabs, laths, etc.) is greatly obstructed.

The erection of rather considerable installations using wood fuel for a paper trust in the central industrial regions of the Union of Socialist Soviet Republics induced the latter trust jointly with the Thermo-Technical Institute to seek for other means to give a rational solution to the problem, so that wood fuel could be efficiently consumed in powerful plants with a capacity of ten to fifteen thousand kilowatts and more. The idea came to make use of fuel wood artificially split into chips by means of chopping machines just as this is done in the cellulose industry, rather than burn logs as is done generally.

On request of the above paper trust the Thermo-Technical Institute has worked out the designs of such plants and has carried out a series of experiments both at its own experimental station and at the paper mill "Sokol" belonging to the aforesaid trust.

These experimental researches have been recently completed and they have given full evidential support to the initial presumptions. The problem of efficient wood fuel combustion in large-scale boiler houses may now be considered altogether solved.

As both calculation and experiment in the Russian paper industry show, the cost of chopping, including also interest on capital invested and depreciation of initial costs, comes up to about 2 roubles per cubic sajene or about 50 copeck (25 cents) per ton of chips obtained with a power consumption of about 7.5 kilowatt-hours per ton of chopped wood.[1]

Since it is quite possible to subject whole trunks to chopping and thereby eliminate expenditure on sawing and splitting, which amounts to no less than 50 copeck per ton, we find that the cost of chip-fuel is practically the same as that of firewood, i.e. the chopping of the former involves no extra expenditure.

Further, the chips prepared are fed into the bunker either through pneumatic conveyors or by mechanical means exactly as this is done in the case of coal.

Thus, the use of chip-fuel permits a complete mechanization of fuel handling and accordingly helps to save costs.

For the burning of chips we used chain-grates with sectional air distribution.

From the standpoint of efficiency, it may be stated that the combustion of chips on a chain-grate runs with considerable economy, yielding a comparative furnace efficiency of no less than $\eta_n^g = 88.5$ per cent.

The combustion of chip firewood on chain-grates, yields an efficiency equal to that obtained when burning firewood in shaft furnaces. Chip combustion, however, has the most important advantages of allowing a complete mechanization of both conveyance and combustion of wood fuel and also the reduction of necessary staff to a strict minimum.

The combustion of firewood in the form of chips has entirely solved—

[1] It would perhaps be more correct to calculate for volume instead of weight of wood chopped, in order to obviate the influence of the varying moisture factor.

both from a technical and economical standpoint—the problem of wood fuel combustion in the largest power plants.

Moreover, the turning of wood pulp into chips will present an excellent opportunity of mastering the combustion of most varied kinds of wood refuse. Branches, refuse of sawmills and that of other woodworks, may be converted into uniform fuel, suitable both for transportation and combustion.

We therefore hold that this method of firewood combustion elaborated by the Thermo-Technical Institute jointly with the paper trust, will soon conquer a vast field of practical application due to its obvious advantages and economy.

The above considerations justify our fundamental conclusion that *firewood, so far from being second-rate fuel,* presents an excellent type of combustible material allowing a high degree of combustion efficiency.

Table II presents, in the first place, a complete heat balance for each kind of fuel, drawn according to the net calorific value of working fuel, Q_n^f; the relative efficiencies referring to the gross calorific value are given in parallel. This table requires the following explanation.

For each kind of fuel the respective values of the rate of heat liberation per unit grate area, $\frac{Q}{R}$, are specified. The above ratio represents the value which is to be recommended for the combustion of different fuels on mechanical grates in actual practice, from the standpoint of both technical economy of combustion and commercial advantage, i.e. taking into account the cost of the plant. Therefore, the figures contributed should be considered as a certain practical limit of the rate of heat liberation per unit grate area, in excess of which the economy of the process usually exhibits a brisk depression. Chiefly this is due to considerably increased losses both due to combustible escaping in flue dust and partly being wasted in clinker.

Next, the values of the normal rate of heat liberation per unit furnace volume, $\frac{Q}{V}$, specify the practical limit which should be adopted lest an appreciable loss due to chemical incompleteness of combustion, q_3, should arise. For all pulverized fuel furnaces long-flame burners are adopted in preference to turbulent burners, so as to obtain the most definite and reliable characteristics of the individual kinds of fuel, since the design of turbulent burners considerably affects

the results obtained, which, of course, may prove to be appreciably raised over the figures given in Table II.

Passing on to the different items of loss involved in the combustion process, it is worth mentioning that the values of the air excess coefficient at boiler outlet of different kinds of fuel, are on the whole rather close, fluctuating in the neighborhood of $\alpha_b = 1.4$. A marked increase of the coefficient of air excess is observed exclusively in mechanical stokers for burning either culm or brown coals containing a great percentage of impurities.

The loss through the chemical incompleteness of combustion, q_3, proves to be uniform for all kinds of fuel, provided the combustion chamber is properly sized and the rate of heat liberation, $\frac{Q}{V}$, duly adjusted in accordance with the data mentioned above.

As to the losses on dropping through the grate (siftings), q_3, this magnitude is determined with respect to improved modern designs of either chain grates or mechanical stokers which eliminate any considerable sifting.

In the practical combustion of slack, non-caking fuel on chain grates of more primitive designs, it is possible of course, to meet with higher values of sifting losses; e.g., it has been often observed that the combustion of such kinds of fuel on simple chain grates involves sifting losses amounting from 10 to 15 per cent.

Loss in clinker, q_A, in mechanical stokers in the first place depends upon and varies with, the ash contents of the fuel. Moreover it is dependent on the character of the ash and chiefly on the fusion point of the latter. For any particular kind of fuel, therefore, the q_A, value is practically liable to fluctuate. The characteristic magnitude defining the clinker loss is represented by ratio:

$$x_A = \frac{q_A}{A^d/100 - A^d},$$

it being easy to prove that the loss in clinker, as calculated in terms of gross calorific value, is generally expressed by the following formula:

$$q_A = 100\, a_A \cdot \frac{A^d}{100 - A^d} \cdot \frac{c}{100 - c} \cdot \frac{Q_A^b}{Q_f^b} \text{ per cent.}$$

where a_A = the ratio of the ash contained in clinker to that contained in the fuel,

A^d = ash percentage in absolutely dry fuel,
c = percentage of combustible matter in clinker,
Q_A^b = calorific value of the combustible matter of clinker
Q_f^b = calorific value of the combustible matter of the fuel consumed.

The calorific value of the combustible matter of both clinker and fuel depends on the properties of the fuel.

Quantity, c, which characterizes the degree to which clinker is burnt out, also depends on the fuel, the design of the furnace and its rate of heat liberation.

Ratio, a_A, is dependent on the amount of ash both escaping with flue dust and sifted through the grate, which ultimately may be traced to design and rate of heat liberation of furnace and to kind of fuel employed.

Thus, the product

$$x_A = 100\, a_A \cdot \frac{c}{100 - c} \cdot \frac{Q_A^b}{Q_f^b}$$

may be chosen as the characteristic value standing for the completeness of clinker burning out.

Now on the ground of rich experimental evidence derived from working with best up-to-date furnace designs, we have learned that the value x_A will fluctuate within the following limits:

Peat and brown coals	$x_A = 0.05$–0.15
Bituminous coals excepting lean coal	$x_A = 0.10$–0.15
Sorted anthracite	$x_A = 0.35$
Lean coal and anthracite culm	$x_A = 0.75$

The losses with flue dust q_c depend on the one hand on the properties of the fuel used viz., caking power, and chiefly contents of fines and on the other hand on the furnace load. The magnitude of the loss tends to increase as both the rate of heat liberation per unit grate area and that per furnace volume assume higher values.

Having thus ascertained the individual items of loss involved in the combustion process, we have further determined the comparative gross efficiencies of the furnace ν_{fn}^g reckoned after the net calorific value of the fuel, while the comparative efficiencies ν_{fg}^g gross, computed after gross calorific value are similarly produced in parallel.

Further Table II shows the amount of energy consumed on the furnace proper, this item being reduced to actuating the stoker and

the forced draft-fans when mechanical stokers are made use of. As for pulverized fuel installations, here only the energy consumption for the preparation of powder and conveyance has been accounted for. Thus, such items as energy-consumption in induced draft-fans have not been incorporated. The consumption of the furnace proper i.e. that consumption of fuel that is required to supply for the above outlay of energy, or in the instance of steam-oil atomizers, that required on oil pulverization is computed on the understanding that the heat expenditure of the steam be equal to 3100 calories per kilowatt hour.

Subtracting the percentage of furnace self consumption from gross furnace efficiency we obtain the comparative net furnace efficiencies again reckoned after gross ν_{fg}^{n} and net ν_{fn}^{n} calorific values.

Computations now enable us to draw a series of conclusions with respect to the comparative technical efficiency of the combustion process when different kinds of fuel are charged and various methods of combustion employed.

As may be seen from Table II, the economy of combustion of fuel (especially non-caking, rich in ash and slack) in mechanical stokers materially depends upon mechanical losses, q_4, and, in particular, upon the losses with flue dust q_c which are usually underestimated. The latter factor, q_c, may produce a considerable effect even in the instance of pulverized fuel stokers when either the fineness of grinding is insufficient or the rate of heat liberation per unit furnace volume, $\frac{Q}{V}$, becomes excessive. Therefore, for the case of long-flame burners and rate of heat liberation $\frac{Q}{V}$ = 250,000 calories per cubic meter per hour, the experiments of the Thermo-Technical Institute supply the following values obtained for loss, q_4:

	RESIDUUM ON SCREEN NO. 200	q_4
	per cent	*per cent*
Anthracite culm	25–30	30
Caking coals	10	11
Free burning coal	22	12

For the purpose of attaining economy in the combustion of pulverized anthracite in particular, sufficiently fine grinding is highly essential. Numerous experiments of the Thermo-Technical Institute

have shown that when anthracite culm is consumed in pulverized form with rate of heat liberation, $\frac{Q}{V}$ = 100–120 thousand calories per cubic meter per hour q_4 assumes the following values:

Residuum on No. 200 screen being 13–15 per cent..q_4 = 3.5 per cent
Residuum on No. 200 screen being 30 per cent.....q_4 = 10.0 per cent

The next conclusions to be derived from table II is that *there appears no tangible reason for the pursuit of very low coefficient of air excess in combustion chamber*, α_f, since practically it is hard to operate the furnace at α lower than 1.3 to 1.35, without appreciable losses through chemical incompleteness of combustion. On the other hand, the decline of α within the usual limits affords, for brown coals and bituminous coals, a saving from losses due to flue gases, q_2, amounting to 0.5 – 0.6 per cent only (when $T-t$ = 150°C).

For the same reason it is clear that *the principal advantage of the pulverized fuel furnace over the mechanical stoker does not lie in the lowering of the coefficient of air excess, but consists in the reduction of mechanical incompleteness of combustion*, q_4.

As to the reduction of the coefficient of air excess, α, it is more advisable to limit the air leakage at the boiler setting—which usually increases the magnitude α between the furnace and the end of the installation—by adopting air-tight designs of setting and by maintaining its compactness.

Next, on comparing the economy of mechanical stokers consuming different kinds of fuel, it becomes evident that *the comparative efficiency of stokers generally falls as the content of volatiles in the combustible matter of fuel decreases;* viz., the maximum efficiency is obtained from peat, while the minimum values are observed when low volatile coals and anthracites are consumed. Besides, the mechanical stoker efficiency naturally decreases as the ash content of fuel rises. The influence of ash content is comparatively low with fuels having great content of volatile matter, whereas when the fuel is low in volatiles this effect becomes very material.

The high ash content of fuel therefore presents the principal obstacle to the economy of combustion in mechanical stokers when low volatile fuels (as anthracite and lean coals) are consumed.

According to its value the comparative net efficiency of all fuels is distributed as shown in Table III.

Thus, the mechanical stokers completely master the combustion

of peat, firewood and pure brown coals, whereas low volatile coals, anthracite culms, bituminous and brown coals with high ash content display a very low efficiency. The difference between the extreme values of efficiency for mechanical stokers is very great, fluctuating within the limits of 88.9 per cent (value for peat) to 61.5 per cent (value for anthracite culm).

The comparative efficiency values of pulverized fuel furnaces fluctuate within much narrower limits, viz., from 90 per cent (for caking coals) to 85.5 per cent (for impure brown coals).

TABLE III

FUEL	COMPARATIVE NET EFFICIENCY	
	Mechanical	Pulverized
1. Mazout, mechanical atomizers	92.0	
2. Caking coals		90.1
3. Mazout, steam-jet atomizers	89.0	
4. Dry, long-flame coals		89.4
5. Low volatile coals		89.0
6. Peat	88.9	
7. Brown run-of-mine clean coals		88.6
8. Peat		88.2
9. Firewood	88.1	
10. Caking coals	87.8	
11. Brown run-of-mine clean coals	87.2	
12. Sorted anthracite		86.7
13. Anthracite culms		86.6
14. Fines of brown slack coals, rich-in-ash		85.6
15. Dry, long-flamed coals	84.7	
16. Anthracites screening	83.0	
17. Fines of brown coals, rich in ash	81.1	
18. Lean coals	79.0	
19. Anthracite culms	61.5	

Furthermore, Table II permits a comparison between mechanical stokers and pulverized fuel furnaces with regard to their technical economy. The pulverized fuel furnace is assumed to be of the unit system and without driers for fuels whose moisture is specified in the table. Such assumption is fully justified by the last tests of the Thermo-Technical Institute which have proved it fairly possible, when ventilating the mill with hot air blast of the temperature 200°C. to grind Sub-Moscow brown coal containing 35 per cent moisture, the fineness of grinding being very satisfactory and the increase of

energy consumption per 1 per cent increase of moisture being relatively low, viz., 0.33 kilowatt-hour per ton on the average.

Likewise, the results of the combustion of undried brown coals of the same grades have been quite satisfactory. For example, with long-flame burners and at a rate of heat liberation per unit furnace volume of the order of $\frac{Q}{V} = 150{,}000$ calories per cubic meter per hour, the efficiency of pulverized impure brown coals (Sub-Moscow Basin) has remained practically constant within the range of moisture varying from 15 to 35 per cent, the process of combustion being altogether steady. The chosen type of pulverized fuel installation is, as shown below, the most economic one, since it affords the minimum cost of plant and the minimum value of operating expenses on fuel combustion. This type, therefore, is selected as a comparison basis in Table II.

On comparing the technical economy of mechanical stokers and pulverized fuel furnaces according to the comparative net efficiency, i.e., taking into account additional fuel expenditure on the energy consumed either by mechanical stoker or pulverized fuel furnace, we are in a position to state the following conclusions:

Fuels with high contents of volatile matter and low in ash afford but insignificant saving—about 1 per cent—and occasionally require even additional consumption of fuel, when the combustion is carried on in pulverized form, as compared with the combustion on mechanical stokers. For instance the combustion of pulverized peat requires additional fuel consumption of 0.8 per cent as compared with mechanical stokers. Clean brown coals afford an economy in favor of pulverized combustion of 1.6 per cent only. The saving attained for clean, caking bituminous coals when burnt in pulverized form is likewise low; it assumes the figure of 2.7 per cent. Dry, long-flame coals, sorted anthracites and impure brown coals afford 4.5 to 5.5 per cent saving (about 5.0 per cent on the average) in favor of pulverized fuel furnaces. The maximum saving in pulverized fuel combustion is obtained with low volatile coal (13 per cent) and especially with anthracite culms in which instance the economy reaches as high as 42 per cent.

From the consideration of these data it is apparent from the standpoint of technical economy, that *the combustion in pulverized form affords the maximum economy in the case of anthracite culms and low volatile coals, whereas for peat and pure brown coals the saving is*

negligible even assuming occassionally negative values. Other kinds of bituminous coal as well as impure brown coals occupy an intermediate position.

III. Relative Cost of Installations for Fuel Combustion

In accordance with the numerous estimates which have been at the author's disposal, it has been possible to infer, rough as it may be, a schematic comparison of different fuels and furnaces with regard to the initial cost. In this outline—as regards pulverized fuel installations,—all cost of the coal pulverization equipment is estimated, including also burners; for mechanical stokers, the cost of the stoker itself, as well as that of the forced draft fans fitted with motors, is computed.

In both cases the costs of combustion chamber, i.e., furnace setting has been excluded from comparison, and this for two reasons: first as may be seen from the values of $\frac{Q}{V}$, these costs are always very close to one another, and second because they are to a great extent dependent on boiler design, type of combustion chamber and the method of its cooling, i.e., such items as are not directly connected with either the furnace itself, or the kind of fuel employed.

Having decided upon such a line of approach we shall readily see that practically whatever the fuel may be, the cost of a powdered coal installation, without drier per one ton of full capacity of installation will always constitute about 8000 roubles, provided, of course, the unit system is used. As to anthracite fuel installations, the respective cost will rise to 16,000 roubles per ton in one hour.[2]

This constancy of unit price finds an easily working explanation in the fact that as the installation passes on to softer brown coals and peat, the increase of mill capacity is virtually neutralized by the higher moisture content of these fuels, wherefore the output of the mill remains constant barely undergoing some slight fluctuations due not to the specific kind of given fuel but to its individual characteristics, i.e. hardness.

Nothing like this is observed in the case of mechanical stokers. Here cost per square meter of grate area remains practically constant; however it should be borne in mind, that the rate of combus-

[2] In all subsequent computations the rouble is rated = $0.50, i.e., the copeck is equal to 0.5 ¢, — cost of installation being as in the U. S. S. R., i.e., with custom duty, carriage and erection charges included.

tion varies in inverse proportion to the calorific value of the fuel and the magnitude, $\frac{Q}{R}$. Hence it is easy to understand that in the case of mechanical stokers the cost of installation per ton per hour of fuel is the less the lower the calorific value of fuel and vice versa.

That is why the cheapest installation costs per ton of fuel burnt per hour are obtained when operating on peat, firewood or Sub-Moscow coal and inversely when fuels with high calorific value and low ratings of $\frac{Q}{R}$ are employed, the cost of furnace performance is accordingly raised, reaching its maximum in the case of low volatile coals and anthracites.

When we come to compare the costs of mechanical stokers and powdered fuel furnaces, we shall not be slow in ascertaining the fallacy of the widespread opinion to the effect that the latter always turn out to be more expensive than the former, i.e., the mechanical stoker. The ratio of costs always depends on the properties of fuel; thus, a powdered fuel furnace will always come up to a higher figure when peat or brown coals of a low calorific value are employed (the cost is even double in the instance of peat); inversely this furnace as compared to mechanical stokers stands to much greater advantage in the case of bituminous coals generally and lean coal in particular, in which latter instance costs are cut 2.5 times; finally when brown coals of high calorific value are made use of, the costs of both types are found to be nearly equal.

IV. Comparative Economy of Mechanical Stokers and Pulverized Fuel Furnaces for Burning Typical Fuels

In order to ascertain the comparative advantages of different methods of fuel combustion, it seems essential to carry out a purely economic computation, to determine the cost of combustion of one ton of fuel burnt in accordance with different methods. In the present paper we mainly intend to compare the relative profitableness of burning different kinds of fuel on mechanical stokers and in pulverized form. In order to insure greater uniformity and provide for easy comparison the following data have been selected to underlie all subsequent computation.

In accordance with Russian conditions fuel costs are understood = 0.3 copecks per thousand calories; number of hours for utilization of indicated furnace capacity n = 4000, this latter figure agreeing

with furnace installation load factor 0.46; rate of interest and depreciation on capital invested, 16 per cent.

When computing the relative items of expenditure involved in the combustion of individual kinds of fuel we have purposely set aside and excluded from calculation such costs as are not directly connected with furnace work, Thus, only the following items have been incorporated: labor costs in pulverizing plant operation, materials and maintenance costs involved in the mechanical equipment of the furnace. The costs of maintenance of combustion chamber (i.e. upkeep of brickwork), boilers, etc. and also firemen's wages have been excluded. The latter item falls under the head of boiler attendance and does not depend on the furnace proper, be it a mechanical stoker or a pulverized fuel furnace.

As will be easily conjectured from what follows below, the cost of energy is an important factor for all final conclusions and bound to underlie all computations. In fact, all calculation is carried out on the presumption of two different costs of energy, viz.: first the rate of 4 copecks per kilowatt hour (the lump selling price of Russian generating plants) and second, 1 copeck per kilowatt hour, which roughly corresponds only to the cost of fuel consumed in producing this energy. The latter method has a vast range of application for the energy expended on the requirements of the generating plant itself. Personally we would deem it more advisable to reckon the cost at selling price, viz., about 4 copecks per kilowatt hour, since not only the cost of fuel, but also other items of expenditure should always be incorporated in the cost of energy production. This is all the more so since most generating plants, and especially Russian ones, are often overloaded and the energy consumed by the plant proper and particularly the furnace installation might easily be marketed at selling price.

We have accounted for the different items of operating and maintenance costs on the ground of the rich experience accumulated by Russian and mainly American plants. However, when making use of the operation data of American plants we have not only just translated the respective cost figures into Russian currency at the rate of exchange of the rouble. Far from that, it was found expedient to take into consideration such factors as the differing costs of labor and material and also other conditions that were found to be at variance in the Union of Socialist Soviet Republics and the United States of America. The results of comparative computation are shown in Table IV.

TABLE IV

Comparative Commercial Economy of Mechanical Stokers and Unit Pulverized Fuel Systems for Typical Fuels

			Firewood (chips)	Peat		Brown coals				Bituminous coals						Anthracites			
						Run of mine, low-in-ash		Fines, rich-in-ash		Dry long-flame		Caking		Low volatile		Screened		Culms	
				Pulverized	Mechanical	Pulverized	Mechanical	Pulverized	Mechanical	Pulverized	Mechanical	Pulverized	Mechanical	Pulverized	Mechanical	Pulverized	Mechanical	Pulverized	Mechanical
1. Net calorific value	Q_n^f	cal/kg.	2,700	3,220		4,200		2,690		5,630		7,180		7,430		6,430		5,710	
2. Price of fuel (.3 copeck per thousand cal.)		Rbl/ton	8.10	9.65		12.60		8.10		16.90		21.50		22.30		19.30		17.10/4.0	
3. Comparative gross efficiency of installation			86.3	88.1	87.1	88.1	85.4	86.0	79.4	88.6	82.9	88.8	86.0	87.6	77.2	85.8	82.1	85.7	59.7
4. Comparative net efficiency of installation			86.1	86.2	86.9	86.6	85.2	83.6	79.1	87.4	82.7	88.1	85.8	87.0	77.0	84.7	81.0	84.6	59.5
5. Comparative cost of equipment per 1 ton/hour installed capacity			6,000	8,000	4,000	8,000	9,300	8,000	6,000	8,000	11,300	8,000	12,000	8,000	19,800	16,000	14,300	16,000	15,200
Cost of combustion per 1 ton powder																			
6. Over expenditure of fuel for mechanical stoker					1.2		3.2		8.3		6.9		3.3		13.5		5.7		43.5
7. Interest on capital invested and depreciation			24	32	16	32	37	32	24	32	45	32	48	32	79	64	55	64	61
8. Operation and maintenance cost			9	17	7	18	12	20	9	20	14	20	18	20	23	45	17	40	18
9. Energy at the rate of 4 cop/kwh			8	80	9	80	12	84	9	84	14	60	16	60	16	88	15	80	18
10. Comparative cost of combustion per 1 ton fuel fired			41	129	32	130	61	136	42	136	73	112	82	112	118	197	87	184	97
11. Same per 1 ton powder			—		32		63		45		78		85		134		92		138
12. Cost of over expenditure of fuel for mechanical stoker per 1 ton powder			—		11		40		67		116		71		301		110		744/174
13. Total comparative combustion cost per 1 ton powder			—	129	43	130	103	134	112	136	194	112	156	112	435	197	202	184	882/312
14. Same at the energy rate of 1 cop/kwh			(35)	69	36	70	94	73	105	73	183	67	144	67	421	131	190	124	863/293

All computation has been made for 1 ton fuel of burnt, after which in order to obtain greater facility in comparing mechanical stokers and pulverized fuel furnaces the respective values have been refigured as for 1 ton of powdered fuel, the difference in fuel consumption for these two types of furnaces being also duly accounted for. As the introduction of the full cost of fuel would have exhibited a quantity greatly exceeding the other constituents of operating costs and, thus, a seeming disproportion might have been observed when making the above comparisons, we have barely accounted for the cost of excess fuel expended for mechanical stokers as against pulverized fuel furnaces.

Thus, the ultimate figures incorporate the following comparative costs: (1) interest on capital invested, (2) depreciation of furnace installation, (3) maintenance, and (4) energy consumed by furnace. We have also added hereto in the case of mechanical stokers the cost of excess fuel as compared with pulverized fuel furnaces.

The figures arrived at help to visualize those particular items that are immediately involved in different methods of burning fuel. They are produced in such a form that the reading of our data should in no way be clouded by the presence of such constant items which are not immediately dependent on the given type of furnace.

Such a computation is drawn on somewhat a rough outline and it perhaps may be qualified as conjectural, yet it affords ample possibilities for reaching a series of quite definite conclusions through which the comparative economy of these two kinds of furnace becomes perfectly evident.

In the first place it will be readily seen from Table IV that a general preference given to one or other of the two methods of combustion is totally and wholly out of the question.

The choice of mechanical stoker or pulverized fuel furnace virtually depends on the properties of fuel, though the general economic conditions, viz., ruling fuel prices, load factor, labor costs, price of energy, etc., should also be taken into consideration.

To simplify computation the latter factors have been understood as constant and they have been selected in accordance with the prevailing Russian conditions. It should be remembered in this connection that the heat values of fuel are fairly high in this country while equipment costs come up to about 50 to 70 per cent above foreign ones, since carriage expenses and custom duty have to be added to the initial price.

As we examine the individual items of comparative expenditure, we shall not be slow to observe the tremendous importance of energy cost for pulverized installations. With rates at 4 copecks per kilowatt hour, this cost averages in the neighborhood of 50 per cent of the general expense of fuel combustion. Even in those cases when energy consumption amounts to but 1 copeck per kilowatt hour the share of this item is very considerable, constituting about 22 per cent of the sum total of all costs involved in pulverized fuel combustion.

Hence, it will be clear that the commercial efficiency of a powdered fuel furnace as compared to a mechanical stoker, to a greater extent hinges on energy rates. The conclusions in this field are often subject to the existing energy price.

Now if we compare expenditures involved in burning fuel by means of the two types of furnaces being examined, while assuming a uniform rate of 4 copecks per kilowatt hour we shall reach the following conclusion (cf. Table IV).

The combustion of lump peat in pulverized form is by all means unprofitable since the expenses increase three-fold (129 copecks per ton) as compared with mechanical stoker (43 copecks per ton); given such rates of energy, pulverized combustion appears just as unpractical in the case of brown coals, even with high ash content, since an excess-expenditure of 20 to 25 per cent as against mechanical stokers is again to be found in this instance. And inversely, anthracite culm, on being pulverized, becomes a most profitable fuel: combustion costs are lowered 4.5 times as against mechanical stokers, the heat price of culm being (in common for all fuels) 0.3 copecks per thousand calories.

Furthermore, even if the rates for culm rule extremely low, being say at 0.07 copecks per thousand calories the advantage of a powdered fuel furnace is still altogether doubtless, since the pulverized fuel furnace is able to cut costs 70 per cent (312 copecks per ton against 184 copecks per ton).

Thus, it *undoubtedly appears preferable to burn anthracite culm in pulverized form.*

The pulverized fuel furnace has also a considerable advantage when burning low volatile coals. Costs are accordingly cut 4 times as against mechanical stoker.

The same holds true also in respect of the remaining groups of coals, the handling of which by mechanical stoker involves 40 per cent higher costs than if they are burnt in a pulverized fuel furnace.

Finally, nearly full equilibrium is observed with sorted anthracite when both types afford practically the same economic results.

Now, if the cost of energy be reckoned at copeck per kilowatt hour, the advantage will shift still more in favor of pulverized fuel furnaces.

Thus we find that in all instances, with the single exception of peat, pulverized fuel furnaces are the most profitable. Maximum profit may be realized in the use of anthracite culms and lean coals; all other types of coals give more than double the saving with pulverized furnaces, and an appreciable economy is afforded with all brown coals and sorted anthracites.

But the combustion of pulverized peat is unprofitable—expenses are doubled in comparison with firing it in mechanical stokers.

We thus see that conclusions and deductions are liable to vary, depending on local economic circumstances. However for the average prevailing conditions in the Union of Socialist Soviet Republics the general inferences are perfectly clear and they may be briefly summed up as follows:

Pulverized combustion of lump peat is certainly disadvantageous; the same had better be burnt in mechanical stokers. Whether it would be reasonable to employ pulverized fuel furnaces for brown coal and screened anthracites appears doubtful; the same holds true expressly in regard to clean brown coals and at high energy prices. As regards moist and clean brown coals, their pulverized combustion is decidedly unprofitable, as it involves a series of surplus costs for the installation of a drier, its attendance and maintenance and it is further connected with considerable loss of fuel. Inversely, it is certainly advantageous to burn anthracite culms and lean coals in pulverized form instead of using mechanical stokers. Similarly, the pulverized fuel furnace has a decided advantage for bituminous coals.

We may summarize our conclusion on the respective advantages of both types of furnace in the following terms:

The profitability of a pulverized fuel furnace increases as the volatile matter content of fuel tends to decline, also, as the ash constants increases and, finally, as the moisture percentage dwindles down. It is therefore, as a rule, more profitable to burn peat and moist clean brown coals in mechanical stokers, and, inversely, anthracite culm and lean coals should by all means be burnt in pulverized form. Other kinds of coal, sorted anthracites and impure brown coals take the middle place, their respective advantages determined by economic conditions tend-

ing either towards the mechanical stoker or the pulverized fuel furnace, with a decided overweight in favor of the latter particularly in the case of dry long-flame and caking coals.

V. CENTRAL SYSTEM VERSUS UNIT SYSTEM IN PULVERIZED FUEL PLANTS

All the preceding conclusions and inferences referred solely to the unit system of powdered fuel plant without driers, since it is this system that we consider the most efficient for pulverized fuel com-

TABLE V

	PER 1 TON/HOUR INSTALLED MILL CAPACITY		PER 1 TON/HOUR UNINSTALLED BOILER ROOM CAPACITY
	Unit system	Central system	Central system
			rbls/tons
Mills inclusive of exhausters and motors	6,000	6,000	4,500
Transport of powder	0	900	700
Bunkers for powder	0	1,800	1,800
Feeders	0	3,000	3,000
Long-flame burners	1,000	1,000	1,000
Total mechanical equipment	7,000	12,700	11,000
Erection	1,000	2,000	1,700
Total mechanical equipment plus erection	8,000	14,700	12,700
Increased cost of building	0	2,000	1,500
Grand total	8,000	16,700	14,200

bustion. In the present chapter we shall endeavor to give this statement full evidential support.

Cost of Plant. The itemized costs of a central system (bin and feeder) and of a unit (direct fired) system calculated for 1 ton per hour output are to be found in Table V. The table shows:

1. Cost figures per ton per hour of installed capacity of powder-preparing plant.

2. Same per ton per hour installed capacity boiler plant.

Both figures coincide for unit systems, since the installed capacities of the powder-preparing and boiler plants may be assumed equal.

Inversely, if roomy bunkers for holding the powder are available,

ample possibilities are afforded for equalizing the load of the powder-preparing plant and accordingly decreasing its installed capacity as compared to that of the boiler plant. Taking into account the typical load graphs of large plants under Russian conditions, we estimate this possible lowering of installed capacity of powder-preparing plant about 25 per cent below installed capacity of boiler room, i.e., as compared with unit plant in respect of mill, powder transport system and drier.

Besides, to the cost of the central system, there should be added the cost of drier plant, the latter subject to considerable variations, depending on the moisture content of various fuels.

An alternate in the design of the central preparation system is to be found in plants without driers, where the drying is performed within the mill itself by means of ventilation by hot air or gas. Accordingly the output of mill is apt to undergo changes depending on the properties of different kinds of fuel and especially their moisture content. Hence, variations in the cost of mill and energy consumption are liable to incur.

Now, so that we might the easier account for all these factors, let us make the necessary computations for three types of pulverized fuel plants and four typical fuels. These calculations are summed up in Table VI.

It will be readily seen from this table that, *despite reduced costs on mill, a central plant with drier, always involves greater initial costs than one without drier, whence it follows that the elimination of the drier and the performance of drying within the mill are fully justified.* This tendency has already become perfectly manifest and the firms engaged in the manufacturing of pulverized fuel equipment have not been slow in adopting the new course.

Further, comparing the respective initial costs of the two systems, we see that *in the case of brown coals and bituminous coals even the cheaper type, of the central system, i.e., that without drier comes out to be nearly 80 per cent more expensive than the unit system.* But if we speak of the heretofore widely used standard central system with drier, it is worth mentioning that its cost exceeds that of the unit system more than twice. And finally, even the central preparation system deprived of drier, i.e., in its very cheapest form, always comes to be more expensive than the unit system in initial costs.

Thus, *from the standpoint of initial costs all advantages are on the side of the unit system.*

TABLE VI

COMPARISON OF DIFFERENT SYSTEMS OF FURNACES WITH REGARD TO COMMERCIAL EFFICIENCY

	BROWN RUN-OF-MINE CLEAN COAL	FINES BROWN COAL, RICH IN ASH	CAKING BITUMINOUS COAL	ANTHRACITE CULM
Ash content of absolutely dry fuel, A^d, per cent	5	31.5	8	20
	roubles	*roubles*	*roubles*	*roubles*
1. Initial cost of installation per 1 ton/hour boiler capacity:				
Powder central system with drier	18,900	18,900	16,600	22,100
Powder central system without drier	14,200	14,200	14,200	18,700
Powder unit system without drier	8,000	8,000	8,000	16,000
Mechanical stoker	9,300	6,000	9,600	15,200
	copecks	*copecks*	*copecks*	*copecks*
2. Cost of combustion per 1 ton moist fuel:				
a. Central system with drier:				
Interest on capital invested and depreciation	76	76	66	88
Operation and maintenance costs	27	28	37	64
Fuel consumption and losses in drier	52	43	47	45/10
Energy at the rate of 4 copecks per kw.-hr.	65	65	81	110
Combustion costs at the rate of 4 copecks per kw.-hr.	220	212	231	307/272
Combustion costs at the rate of 1 copeck per kw.-hr.	171	163	170	225/190
b. Central system without drier:				
Interest on capital invested and depreciation	57	57	57	75
Operation and maintenance costs	30	31	33	65
Energy at the rate of 4 copecks per kw.-hr.	102	102	80	142
Combustion costs at the rate of 4 copecks per kw.-hr.	189	190	170	282
Combustion costs at the rate of 1 copeck per kw.-hr.	112	114	110	171

Energy Consumption. The total energy consumption for grinding pre-dried coal in a central plant is constituted of the following items:

	kilowatt hours per ton
Mill	10.5
Exhausters	4.5
Transport of powder	2.5
Driers	1.5
Feeders, etc	0.5
Fans for primary air	1.5
Total	210

As against this, for unit plants we have an energy consumption ranging from 15 to 21 kilowatt hours per ton depending on properties of the fuel.

TABLE VII

	CENTRAL SYSTEM	UNIT SYSTEM
		copecks per ton
Brown coals and bituminous coals		
Operation labor and materials	18	3
Maintenance	15	17
	33	20
Anthracites:		
Total cost		
Culms	65	40
Sorted anthracite	70	45

Thus, the usual opinion that the fuel load of mills in central preparation system reduces the energy consumption as compared with unit system proves to be incorrect since the saving of energy effected in the mills is more than counterbalanced by great additional energy consumption in central systems.

The central preparation system without driers, so far from effecting the saving of energy, usually involves, with rare exceptions, an increase of total energy consumed due to the extra energy required by mills, in spite of the energy outlay in drying equipment being obviated.

Thus, *in regard to energy consumption, the central systems not only do not present any advantage over the individual ones, but involve extra consumption of energy as compared with unit systems.*

Operation and Maintenance Costs. In accordance with the operation data available, further calculations may be based on the figures given in Table VII.

Thus, in regard to operation costs, the central system proves to be 1.5 times as expensive as the unit system, as it might have been expected beforehand considering the intricacy of the equipment of central systems.

TABLE VIII

	RUN-OF-MINE, CLEAN BROWN COAL	FINES OF BROWN COAL, RICH IN ASH	CAKING BITUMINOUS COAL	ANTHRACITE CULMS*
For the energy at the rate of 4 copecks per kilowatt hour				*copecks per ton*
Powder				
Central system with drier	220	212	231	307/272
Central system without drier	189	190	170	282
Unit system	130	134	112	184
Mechanical stoker	103	112	156	882/312
For the energy at the rate of 1 copeck per kilowatt hour				
Powder				
Central system with drier	171	163	170	225/190
Central system without drier	112	114	110	171
Unit system	70	73	67	124
Mechanical stoker	94	105	144	863/293

* The figures to left of diagonal lines correspond to the price of culm of 0.3 cop/thousand cal; those below the lines correspond to the price of 0.07 cop/thousand cal.

Comparison of Combustion Costs. The results of the calculation of combustion costs based on the same initial data as before, are given in Table VI for different central systems.

Ultimately, for 4 types of installations we have the data given in Table VIII of the relative costs of combustion per 1 ton undried fuel, as referred to different typical fuels.

The final results given in this table allow in the first place, to state with all peremptoriness that of the three types of installations for pulverized fuel *the least advantageous one is the central system fitted with driers, which renders the cost of combustion 2 to 2.5 times as great as that of the unit system.*

The omission of the drier and the adoption of drying carried out within the mill, itself affords a considerable cutting down of combustion costs, though in this case also, *the central system without a drier is always more expensive than the unit one.*

Thus, *in regard to combustion costs, the central system proves to be by far less advantageous than is the unit one;* therefore the tendency to adopt the former is altogether justifiable. During the last few years it has been rapidly gaining general application in the United States of America, where the over-all capacity of unit systems used in industrial plants exceeds that of central systems by 70 per cent. In this field mainly unit systems have been erected in the United States of America within the last years. However, at large central generating plants the central systems still prevail, though during the last two years the development of new installations has also manifestly progressed in favor of unit systems in this field.

From further comparison of central systems with mechanical stokers it becomes evident that *for all fuels, except anthracite culm, the central systems fitted with driers prove to be more expensive in operation than the mechanical stokers.*

Central systems without driers are more profitable than the mechanical stokers in the case of anthracite culm. When either brown coals or peat are burnt, the central systems can in no way compete with the mechanical stokers as well as when caking pure coals are bunt, in which case, however, some advantage may be detected in favor of central systems provided energy is very cheap.

This comparison, though made with regard to Russian conditions only, suggests a definitive conclusion in support of the unit system versus the central one even in its most rational form, i.e., without driers.

Therefore *the general tendency in the near future should undoubtedly be directed towards the further development and perfection of the unit systems.*

The usual arguments against the unit system, are, of course, altogether irrelevant, namely, the rapid wear of high speed mills since the unit system is not intrinsically connected with any particular type of mills, or with high speed mills in particular. The intrinsic peculiarity of the unit system is the direct transport of powder from the mill to the furnace avoiding the intermediate bunkers and intricate feeding devices. When operating unit systems there is no objection,

therefore, to the use of various designs of mills chosen according to the particular properties of the fuel to be ground.

Likewise, one can hardly agree with the assertion that the central preparation systems possess a higher technical economy, i.e., efficiency, as compared with unit plants. If such conditions may exist in practice, this cannot be ascribed to the inherent peculiarities of either system, but is merely due to the fact that the comparison may be based on data obtained from central system plants consisting of modern boiler units with well designed, large combustion chambers, mills allowing of fine grinding, low temperature flue gases, etc., on the one hand, and evidence derived from unit plants of very primitive description on the other. Such a comparison is, of course, incorrect.

One cannot possibly deny that the central system possesses some advantages in the way of convenient and adaptable control. This may, however, afford but an inconsiderable decline of the coefficient of air excess and—as has been stated above—an altogether insignificant rise of efficiency due to reduced losses with flue gases, viz., in the neighborhood of 0.5 per cent. This saving, however, is usually counterbalanced by increased losses of fuel due to the escape of powder from the cyclones of the mills and bunkers; these losses usually exceed 0.5 per cent and more than absorb the saving gained in the above way.

Thus, if central preparation and unit systems are to be compared under equal conditions of equipment, when choosing adequate designs of mills for unit systems, *the efficiencies of both systems may be considered equal*, though some advantage may be assigned to the unit system, since in practice the above losses in cyclones, bunkers, and in other parts of the central system may even reach very appreciable values. Thus, on the ground of data available, we believe that all advantages belong to the unit system, which doubtless has a great future.

SUMMARY

1. In order to insure correct technical comparison of individual kinds of fuel and different furnaces it has been found expedient to introduce the value of comparative furnace efficiency, which has the advantage of rendering in one figure the effectiveness of different furnaces.

2. The following deductions regarding the comparative efficiency

of burning different kinds of fuel can be made on the ground of the vast experimental evidence accumulated by the author:

a. Mechanical furnaces perfectly master the combustion of such fuels that are characterized by a high content of volatile matter and especially of those that are low in ash, notwithstanding the eventual high moisture-content of these fuels. In the latter case greatly improved results are attained by the use of hot blast.

b. Modern mechanical stokers are unable to burn anthracite culm with any degree of economy. Similarly but low efficiencies are obtained when burning low volatile coals in these stokers.

c. When burning lump peat and impure brown coals, pulverized fuel furnaces afford practically no economy as compared with mechanical stokers. The maximum fuel economy for pulverized combustion is obtained when burning low volatile coals and especially anthracite culm.

Thus, the saving in fuel obtained through burning it in pulverized form is the greater the less the volatile content, the more the ash content, and the less the moisture content of the fuel.

3. From among the various existing systems of powdered fuel plants, preference should be ascribed to unit systems without driers. The latter excel central preparation systems in respect to initial cost, energy consumption, and operation costs; and ultimately afford lower combustion costs as compared with central plants.

4. Driers are the least profitable item of a pulverized fuel plant, since they bring about an increase of initial costs and greatly lower the technical and commercial economy of the plant involving, moreover, a number of extra operation expenses and losses of fuel. The elimination of driers, by means of performing the drying within the mill itself is a *sine qua non* condition for the further progress of pulverized fuel installations.

The latest experiments of the Thermo-Technical Institute have proved it quite possible to perform the grinding of brown coals with moisture content up to 35 per cent (hygroscopic moisture about 8 to 10 per cent). The experiments have also ascertained complete possibility of burning the powder obtained without imparing the efficiency of the plant.

5. No general solution can be given to the problem of whether a pulverized fuel furnace or a mechanical stoker be preferred under any circumstances.

The problem depends entirely upon the properties of fuel and economic conditions. Under average Russian conditions the use of pulverized fuel installations may be said to be totally unprofitable only in the case of lump peat and clean moist brown coals, requiring preliminary drying. Inversely pulverized combustion of lean coals and especially anthracite culm is undoubtedly advantageous.

Other kinds of fuel take an intermediate place between the two extremes exhibiting a certain tendency in favor of the powdered fuel system.

Thus, the commercial profitableness of a pulverized fuel furnace as compared with the mechanical stoker increases as the content of volatile matter in fuel decreases and rises with the increase of ash content as well as with the decline of caking power and reduction of moisture percentage of fuel.

THE TRANSPORT OF PULVERIZED COAL

By I. P. Goossens, Dr. Ing.

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Read by Thomas G. Estep, Jr., Associate Professor of Mechanical Engineering, Carnegie Institute of Technology

The practice of firing with pulverized fuel is continually increasing and therefore a critical scrutiny of the methods and costs of the transport of readily burnable pulverized fuel seems to be justified.

Since the introduction of pulverized coal the technical possibilities of its utilization have developed to such an extent that there is hardly any doubt about its practical usefulness. There is nothing entirely new concerning the methods of transporting pulverized coal. The present methods originate from the transport technique for other materials that has existed for many years. Therefore the scope of this article must be limited to the possibilities of the various methods from the viewpoint of their economical importance, without going into technical details. My explanations should therefore determine to a certain extent, the limits of the utilization possibilities of the methods of transportation, in order to make possible a quick survey of the advisability of obtaining the fuel in a ready burnable form or as raw coal.

According to the distance from the producing point to the using point, there must be considered:

The re-transportation (up to about 50 meters)
The long distance transport in pipe lines as well as
The transport in tank cars.

First, taking the short distance into consideration, it may be said that the transporatation of pulverized coal for a distance up to about 50 meters by means of fan air, can easily be done, but the amount which can be transported in this manner is limited to a certain extent by the amount of dust produced. In most cases it is limited to the transport of pulverized coal in a ready burnable mixture, to the point where it is burnt. Either the pulverized coal from the bunker is mixed with the air-current into a burnable mixture by means of a suitable mixing apparatus, or is drawn direct from a unit pulverizer by means of the air-fan and delivered into the combustion chamber. These means of transportation are sufficiently known and give no trouble.

Only one point must be noted. The pipe lines must not only be so designed that the transport speed of the pulverized coal exceeds the back-fire speed, but also that no depositing of pulverized fuel takes place in the pipe lines. Such deposits cause an uneven rate of flow, whereby the burning, with the same amount of air, is subject to great variation. The unevenness can become so great that the success of the pulverized coal firing with completely water-cooled combustion chambers becomes questionable. The smaller the firing, the more care must be taken that through the even rate of flow of pulverized coal the flame preserves itself. It would seem best to convey an even mixture of fuel and air through small pipe lines by means of higher pressure and reduce the velocity in the burner itself rather than to utilize large pipe lines with less velocity. The pulverized coal distribution apparatus and the firing can have a distance of about 50 meters from one another, although such a distance is not advisable, as the manipulation and regulation of the firing is rendered more difficult. It would seem more favorable to erect the mill or the bunker in the immediate vicinity of the firing.

When utilizing the bunker system, the conveyance of the pulverized fuel from a central pulverizer or from a tank car would have to be considered. In this case, large amounts of pulverized fuel would have to be conveyed within a short time. Low pressure air can no longer be used as a means of conveyance, so compressed air must be used. This method of conveyance can be effected in two ways. Either dust-pumps, such as are produced by many firms, are used; or the purely pressure method, the latter having been adopted with the special pulverized fuel tank cars for railway transport. In both cases the compressed air must be absolutely free from water and oil. The apparatus with the dust-pump method consists mainly of the pulverized fuel bunker to the conical end of which is fitted a worm-screw mounted in a casing. This worm-screw is set into rapid rotation by means of a motor. At the end of the worm-screw, compressed air nozzles are arranged, the discharge of which picks up the pulverized fuel as it drops off the screw and carries it through several hundred meters of pipe line by means of the utilized pressure. Pipe line installations of 1,500 meters and above are at present in satisfactory working order. The same result can be attained with lesser means, if the pulverized fuel is forced out of the conical end of a pressure reservoir with the assistance of several compressed air nozzles. The steep conical end of the cylindrical reservoir, which has

an angle of inclination under 50° to 60° to the horizontal, insures a smooth flow of the pulverized fuel. In order to increase the flow of the pulverized fuel at the beginning of the discharge, compressed air is blown through a compressed air nozzle, into the column of pulverized fuel, the conveyer-cock being closed until the reservoir shows a pressure of 1.5 to 2 atmospheres. Then the pulverized fuel conveyer-cock is opened and compressed air is simultaneously blown in above the level of the pulverized fuel. If the pipe lines have the correct diameter, a faultless and rapid conveyance along many hundred meters results. The amount of compressed air used is only about 8 cbm. per ton of conveyed pulverized fuel, which means that it is considerably less than when dust-pumps are used. The quantity conveyed amounts to 1 ton per minute, when 100 mm. (diameter) of connection pipe is used.

The chief additional advantage of the pressure system, contrasted with dust-pumps, is that there are no movable parts which are subject to considerable wear. Furthermore the power consumption for this method is far less than that required for the pulverized fuel pump-system.

In both cases it would be advisable to provide against any possible choking up of long pipe lines, by means of additional air nozzles placed along the lines at a distance of about 50 meters. These additional air-nozzles are easily controlled from the point of conveyance by means of compressed air regulators, or relays. To insure greater safety, two parallel pipe lines can be laid, which absolutely guarantee a continual supply.

By means of contrasting costs, it can be seen that the pure pressure system is superior to the pumping method, with regard to the costs of the plant as well as working costs. The following comparison of costs is based on the conditions prevailing in Germany, assuming that a daily amount of 400 tons (four hundred) of pulverized fuel is conveyed over a distance of 3,200 meters from the pulverized fuel producing station.

Contrasted are: in Schedule I the value of the plants of both systems and in Schedule II the working expenses of both systems.

SCHEDULE I

VALUE OF PLANT

(A) *Pressure System Filling Station*	*Pipe-line Construction*
Bunker plant with scaffolding..... Mks. 39,000.–	2 conveyance pipe lines 100 mm.... Mks. 74,000.–

Compressor plant with electric motors drive 65 KW	Mks. 12,000.–	Compressed air pipe line, together with motors	Mks. 38,000.–
Motors	Mks. 12,000.–	Construction of the pipe lines, together with foundations	Mks. 28,000.–
Erection and Building proportion	Mks. 17,000.–		
	Mks. 80,000.–		Mks. 140,000.–
(B) Bunker plant with scaffolding	Mks. 38,000.–	2 conveyance pipe lines 125 mm	Mks. 105,000.–
2 dust-pumps with electric drive	Mks. 17,000.–	Compressed air pipe line, together with motors	Mks. 50,000.–
Motors	Mks. 10,000.–	Construction of pipe lines, together with foundations	Mks. 30,000.–
Compressor plant with electric drive 65 KW	Mks. 15,000.–		
Erection—Buildings	Mks. 35,000.–		
	Mks. 115,000.–		Mks. 185,000.–

SCHEDULE II

WORKING EXPENSES

These are compiled from:

(1) Depreciation and Interest allotted on 5 years.
(2) Cost of Attendance.
(3) Power Consumption.
(4) Repairs and Miscellaneous.

(A) Pressure System: *(B) Pump System:*

(1) Redemption and Interest 27 per cent per Annum, which means per ton

$$\frac{220000 \,.\, 0.27}{365 \,.\, 400 \,.\, 100} = \text{Mks. } 0.40.7 \qquad \frac{300000 \,.\, 0.27}{365 \,.\, 400 \,.\, 100} = \text{Mks. } 0.55.4$$

(2) Attendance:

2 Workmen at 10.– Mks. per day

$$\frac{6000}{400} = \text{Mks. } 0.15 \qquad \frac{6000}{400} = \text{Mks. } 0.15$$

(3) Power Consumption:
65 KW at 0.04 Mks.
Conveyance 20 t/hr.

$$\frac{65 \,.\, 0.04}{20} = \text{Mks. } 0.13 \qquad \frac{95 \,.\, 0.04}{20} = \text{Mks. } 0.19$$

(4) Repairs etc.:
Mks. 3,000.– per year

$$\frac{300000-}{365 \,.\, 400} = \frac{\text{Mks. } 0.02.1}{\text{Mks. } 0.70.8} \qquad \frac{600.000}{365 \,.\, 400} = \frac{\text{Mks. } 0.03.4}{\text{Mks. } 0.92.8}$$

Summed up: Mks. 0.71 *Summed up:* Mks. 0.93

According to this the cost per ton and kilometer is:
about Mks. 0.22 about Mks. 0.29

From the comparison according to Schedule II it can be seen that the conveyance according to the pressure system is considerably more economical and can be carried out with about three-quarters the costs, reckoned on an average, against the pumping system. With pulverized fuel tank cars the pressure system works faultlessly, as these tank cars are equipped to use this system. Plants using this system have already been erected in which the pulverized fuel is conveyed over a distance of many hundreds of meters.

As a result of the greater economy of the purely pressure system, the fuel can be transported greater distances in competition with conveyance by tank cars on railroads, than is possible with the pulverized fuel pumps. Whether one or another method is more appropriately utilized, in the design of the intersecting points, chiefly depends on the local conditions, which in every case are different. The experiences obtained with the long pipe lines now in construction will determine whether the pipe lines themselves are to be conducted over longer distances than has hitherto been the case. There is however no reason why the pipe line itself should not be constructed up to a distance of 10 kilometers, as the longer the pipe line, the less the cost of transportation per ton per kilometer, because the plant value of the end stations remains approximately the same, notwithstanding whether the pipe line is long or short.

The advantages offered by a central pulverization plant, particularly in larger works where the furnaces are situated far apart are generally so manifold, contrasted with single pulverization plants, that the cost of the conveyance of pulverized fuel in pipe lines is nearly negligible. The conveyance in pipe lines increases the price of the coal per ton kilometer only about 22 to 29 pfennings, which is not even 2 per cent of the cost price of the coal. This increased price is

amply compensated for because the milling costs in a central pulverization plant are lower than if pulverized in many single plants, and because the transport of the raw coal within the works is completely eliminated.

Should distances above 10 kilometers be considered, it is probable that the ground conditions will be such as to leave no other way open than transportation by rail.

The trials conducted for the purpose of transporting pulverized coal in common freight cars were not successful, because the pulverized fuel was partly lost through leaks; and owing to the air currents over the open car, frequent fires from spontaneous combustion occurred. It was therefore necessary to build special cars for this purpose, which also allow the pulverized fuel to be easily discharged. For this either suction or compressed air can be used. The so-called self-discharging tank cars have not been able to hold the field. The suction air method has been found practical at places where the necessary suction plants suitable for this purpose were already in existence. The necessary apparatus for the suction method is far greater than that necessary with the pressure method. Furthermore the emptying of a special pulverized fuel transportation car by means of suction takes much more time than by means of compressed air. To this must be added the fact that the labor operations are far greater and more extensive with the suction method than with the pressure method. Therefore during the last few years, as far as Germany is concerned, orders have been given only for special pulverized fuel transportation cars with pressure discharge.

As a result of many trials, tank cars with upright reservoirs have been selected, similar to the first cars built by Messrs. "Kohlenstaub" of Aachen, Germany. The improvements in this kind of tank car construction consist chiefly in decreasing the dead-weight and thus securing larger capacity for the reservoir. The emptying appliances have also only been subject to a few improvements. The emptying of the cars generally takes place according to the method aforementioned for the discharge of pressure reservoirs. Because of the inclination of 50° of the discharging basin, complete emptying of the reservoir can be secured. The correct size of the pipe line diameter and quantity of air in the nozzles, result in a 27 ton car being emptied in a half hour; and the required compressed air amounts to not more than 8 cbm. per ton of pulverized fuel conveyed. Based on a price of 0.04 mks. per cbm. of compressed air, the transfer

from a pulverized fuel car into an elevated reservoir costs about 0.32 mks. per ton of pulverized fuel. The cost per ton of pulverized fuel, when a special car is used depends on the running time necessary for the journey of the car to the consumer and back to the pulverized fuel contractor. This running time is not only dependent upon the distance, but particularly on the speed the car can develop on the line it runs. It has been found that in a larger factory in Germany the average distance is 37 kilometers and the average running time of the car on this distance is 5.28 days. Based on these figures the cost for the utilization of a special tank car are as follows:
The first cost, end of 1927, for the pulverized fuel cars amounted to:

	Mks.	*Mks.*
For the 2 axled car, 18 tons capacity.....	about 10,500.–	583/ton
For the 3 axled car, 27 tons capacity.....	about 13,500.–	500/ton

The cost per ton of pulverized fuel sold to an average consumer, through the running time of 5.28 days, amounts to:

	With the 18 t. car	With the 27 t. car
Through Capital invested (17 per cent per Annum).....	Mks. 1785.–	Mks. 2295.–
Through Maintenance and Inspection Costs.....	400.–	550.–
Through Insurance.....	65.–	75.–
Total per Annum.....	Mks. 2250.–	Mks. 2920.–
Accordingly the cost per Ton of Pulverized Fuel.....	Mks. 2250.–5.28/	Mks. 2920.–5.28
	365 . 18	365 . 27
	Mks. 1.81	Mks. 1.56
To these costs must be added the costs for emptying per Ton of Pulverized Fuel:		
Attendance and consumption of compressed air in works.....	0.32	0.32
Freight for 37 kilometers inclusive return transport.....	2.49	2.39
	Mks. 4.62	Mks. 4.27
Transport of Pulverized Fuel in Railway cars along a distance of 37 kilometers Uniform average rate per ton and kilometer =	Mks. 0.13	Mks. 0.12

For the purpose of contrasting the three transportation possibilities for a distance of 10 kilometers and with a daily capacity of 400

tons; (pipe lines can without doubt be constructed for this distance,) the following illustration is given (the depreciation for the cars has been allotted a life of 7 years)

SCHEDULE III

	(A) *Pressure Conveyance*	(B) *Pump Conveyance*		(C) *Car Transport*
Filling Station.....	80,000.–	115,000.–		60,000.–
10 K. Pipe Line.....	437,000.–	578,000.–	32 Cars	432,000.–
	517,000.–	693,000.–		492,000.–

Operating Costs:

Depreciation $\frac{517 \,.\, 27}{365 \,.\, 400} =$	0.95	$\frac{693 \,.\, 27}{365 \,.\, 400} =$	1.28	$\frac{492.12}{365.400} =$	0.59
Attendance.....	0.15		0.15		0.15
Power Consumption..	0.13		0.13		0.32
Repairs, etc.....	0.02		0.04	Freight 10 K	1.40
Costs of conveyance for 10 K. p. Ton....	1.25		1.66		2.46

The conveyance by pressure costs over a distance of 10 kilometers are therefore only half as much as the transport by cars. This result can naturally be strongly influenced by local conditions. Every single case is different and requires special consideration. However by contrasting the 3 methods of conveyance, it can be seen that the cost of conveyance of the pulverized fuel through the pressure system is quite reasonable.

Endeavors to reduce the cost of transportation of coal through the utilization of private tank cars and by means of special tariffs for the transportation, have, up to now, been frustrated by the action of the Railway Authorities.

If the price of the pulverized fuel delivered to the bunker of consumer is contrasted with other kinds of coal, all factors must be taken into consideration, and above all things, the fact that the combustion with pulverized fuel generally is more efficient than with any other kind of firing. The continued sale of pulverized brown coal in Germany at a price which almost reaches the price of highly valuable briquets, is a further proof that in the end the cost on a useful heat basis will be the deciding factor.

The cost per ton for a distance of 37 kilometers for the use of the cars alone amounts to 1.74 mks. and that is about 10% of the average value of lump coal. In other words, this means that if the collieries

proceed to prepare their small coal into ready burnable pulverized fuel, without residue, that is, to turn this product into a highly valuable product, they can obtain for it the regular price for lump coal after deducting 10 per cent for the use of the cars and deducting the costs of preparation. It is known that the collieries generally have to sell their small coal at a very low price. The difference in cost between small coal and good coal can be taken at about 50 per cent although definite information is not obtainable, as the sale of small coal is at different prices, even by the same colliery. For instance, the price of small coal suitable for pulverization fluctuates between 6/– and 9/– per tons, whereas 14/– to 18/– per ton is obtained for good coal. The difference between these two kinds of coal can therefore be taken at about 8.5/–. If the costs for the utilization of special cars, or the conveyance costs through pipe lines is deducted, the remaining difference is sufficient to justify the preparation costs of the small coal into pulverized fuel at the collieries. Sufficient proof can be obtained from literature on the subject, that the pulverization costs per ton of coal seldom is more than 2.50 mks. The pre-debiting of the ready burnable pulverized coal, which, for instance, must be transported over a distance of 37 kilometers, consists of the following:

1. Pulverization costs	2.50 Mks.
2. Utilization of special cars	1.74 Mks.
3. Emptying costs	0.37 Mks.
	4.61 Mks.

From this point of view the transportation of pulverized fuel from a central pulverization plant receives increased importance.

It is known that every colliery has a considerable amount of small coal, which has cost the same amount per ton for conveyance out of the mine as good lump coal. And in addition, the picking of small coal often costs more than the sorting of the large pieces. Nevertheless it is generally sold for about one-half the price of good lump coal. The collieries loose an average of 8.50 mks. per ton on the small coal, although the caloric value is little less than that of the lump. If the collieries would take up the preparation of all of their small coal into ready burnable pulverized fuel and first of all use it in their own furnaces, marketing the surplus, I do not think that it would be difficult for them to obtain for this pulverized fuel, the same price as is paid for lump coal.

Having recognized these possibilities, collieries and syndicates in Germany have commenced, not only to prepare and sell pulverized fuel, but also actively to assist in the changing over of the furnaces in many works into pulverized coal firing, by financing such projects. Based on contracts for the delivery of pulverized fuel for many years, it is quite possible for the changing over of the furnaces to be financed by the collieries or syndicates, and this has already been carried out on a practical scale.

These favorable results justify the hope that the conveyance of ready burnable pulverized fuel through pipe lines or by means of special tank cars will, in the near future, become more common.

DISCUSSION

R. C. VROOM (Peabody Engineering Corporation of New York): The paper by Mr. Jefferson and Commander Broshek was of particular interest to me because I have been rather closely associated with the development of pulverized coal firing for marine work. As a representative of the Peabody Engineering Corporation, I had the privilege of being present during the several seagoing tests at the Fuel Oil Test Plant, and in making the first trans-Atlantic voyage on the *Mercer*, as well as one round trip on the *Lingan*, the Canadian vessel which is now burning pulverized coal.

I think the Shipping Board and Mr. Jefferson, and the officials of the Fuel Oil Test Plant should be congratulated on their foresight and on carrying through the experiments to a successful conclusion. I know it has been very difficult at times to carry through this project and I think they should be given every consideration.

I noticed in the paper one item which I think perhaps requires a little further explanation. It was stated that much of the pioneer work has been done by the government and that from now on it devolves upon private interests to carry on. I do not think it has been fully appreciated that private interests have already done considerable development work on their own part. The burners which were furnished the *Mercer*, and have since been installed in the *Lingan* and the tug *Tomaco*, which is being put in commission in Philadelphia by the Reading Railroad, were developed in 1925 by the Peabody Engineering Corporation and had already been in successful operation in a commercial plant before they were supplied to the Shipping Board for test.

The question of distribution in the case of a Scotch marine boiler is infinitely more difficult than it is in the case of an average stationary boiler. That point I think should be brought out. In the Scotch marine boiler, in the first place, the capacities with burner will run as low as possibly 300 pounds per hour. The furnace is only about 3 feet in diameter, 9 feet long and totally water-cooled. Each flame is in a separate combustion chamber. There are several installations using horizontal turbine and firing in stationary practice, where four heats are taken from a single unit pulverizer, but each of these flames discharges into a common combustion chamber, and they in that way assist mutually in their combustion.

The importance of this question of distribution was realized by our company before we submitted equipment for test at Philadelphia, and we not only made an experimental installation on the Scotch boiler with the burners previously developed for stationary work, which proved that pulverized coal could be burned under a Scotch boiler with that type of equipment, but we also did considerable development work with a distributor.

This distributor was a mechanical device, the principle being that a non-homogeneous mixture of pulverized coal would be discharged from the pulverizer, and that a distributing device must be placed in the pipe line which would not only produce at its outlet a homogeneous mixture, but the pipe lines must be so proportioned that the pressure drop through them would give equal quantities of homogeneous mixtures.

The burners and distributors were supplied to the Shipping Board for test at the Fuel Oil Test Plant, and I think it is of great interest to note the equipment on the *Mercer* is essentially the same as originally furnished. I use the word "essentially" advisedly, because certain modifications which it was expected would have to be made, were made in the interior construction of the distributor, but the essential features of a rotating element in the stream of coal for the purpose of producing turbines, were maintained.

I think, therefore, that it should be borne in mind that private interests already have contributed a considerable amount of time, money, and effort to the development of seagoing equipment. Furthermore, the burners, the impact pulverizing, piping, motors, conveyors, were all installed at the expense of our company for the first test in Philadelphia. The test work, of course, was carried on at the expense of the Shipping Board.

Mr. Peabody, who had expected to be present here today to deliver a discussion of this paper in person, was unfortunately detained in New York, and he has asked me to present to you a written discussion of this paper.

ERNEST H. PEABODY (Peabody Engineering Corporation of New York. Written discussion read by Mr. Vroom): The final solution of the difficult problem of burning pulverized coal at high rates in the restricted water cooled furnace of a Scotch marine boiler was brought about by applying the methods of air admission and mixture with the fuel which had for many years been found eminently satisfactory in burning oil fuel under similar conditions.

Therefore, the burner which accomplished this important effect was the vital factor which produced the successful results described by Mr. Jefferson and Commander Broshek and after overcoming seemingly insurmountable obstacles, actually placed pulverized coal fuel on the high seas, as a competitor with oil.

This does not mean that the pulverizer and all the auxiliary equipment for delivering the fuel in the proper state of fineness and at the lowest possible cost to the burners are not important adjuncts, nor that the efficiency or inefficiency in carrying out their functions can be ignored or overlooked in their effect upon the ultimate economic results. High power consumption of the pulverizer, for example, may nullify the gain in efficiency due to the burning of the fuel in the powdered condition.

But the burner was the last essential link in the chain of progress, and all

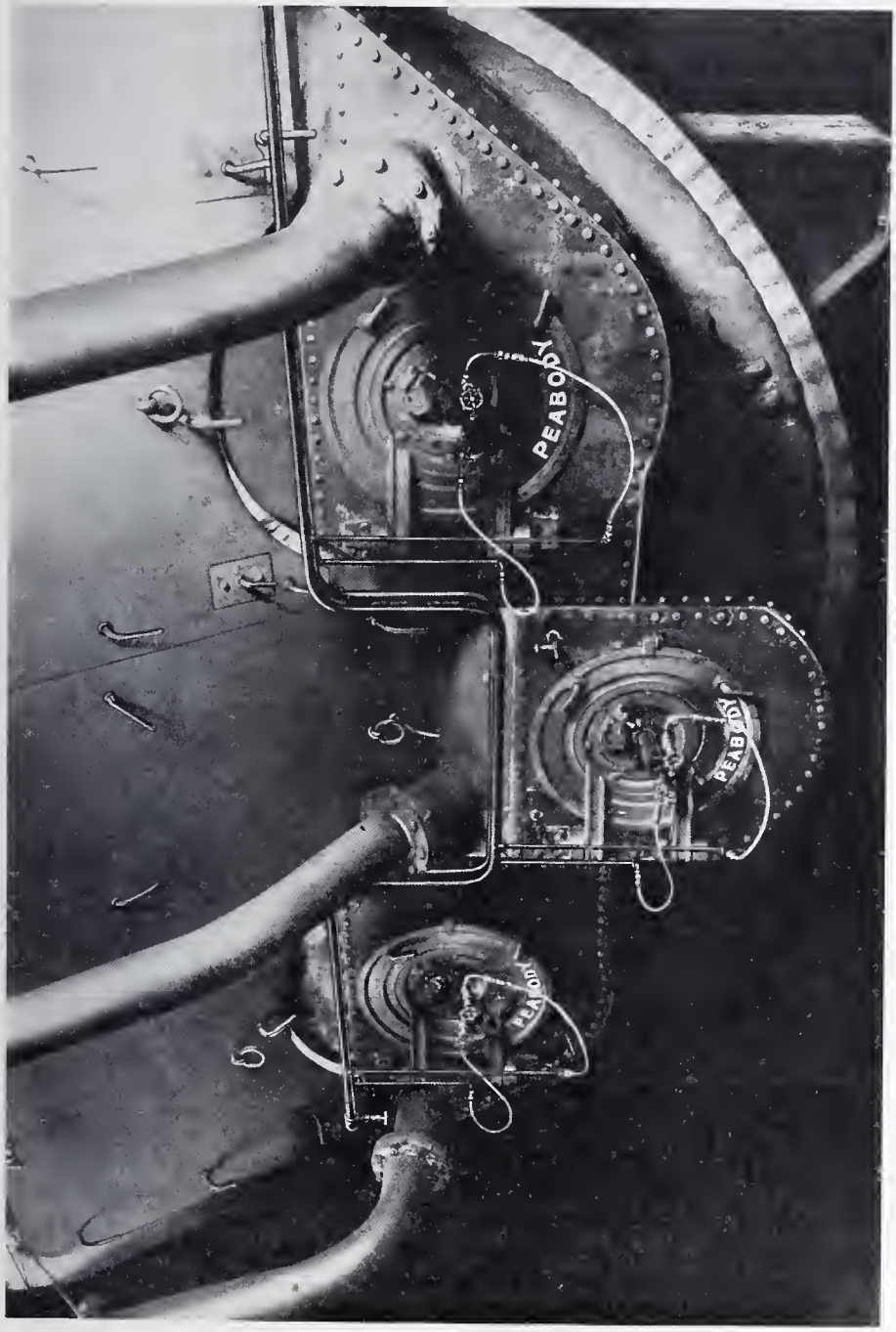

FIG. 1

the older items of equipment had to impotently await the day of its development. The burner, therefore, becomes the focal point of interest in an innovation, the far-reaching effects of which at present can but dimly be foreseen.

The Peabody Coal Burner, tested at Philadelphia and installed on the pioneer vessel using pulverized coal at sea, is combined with the air register which had already demonstrated its value in burning oil fuel. In fact, in order to convert the burners for use with oil fuel, no other change was needed than to place the atomizers in the bearings already provided and to turn off the coal

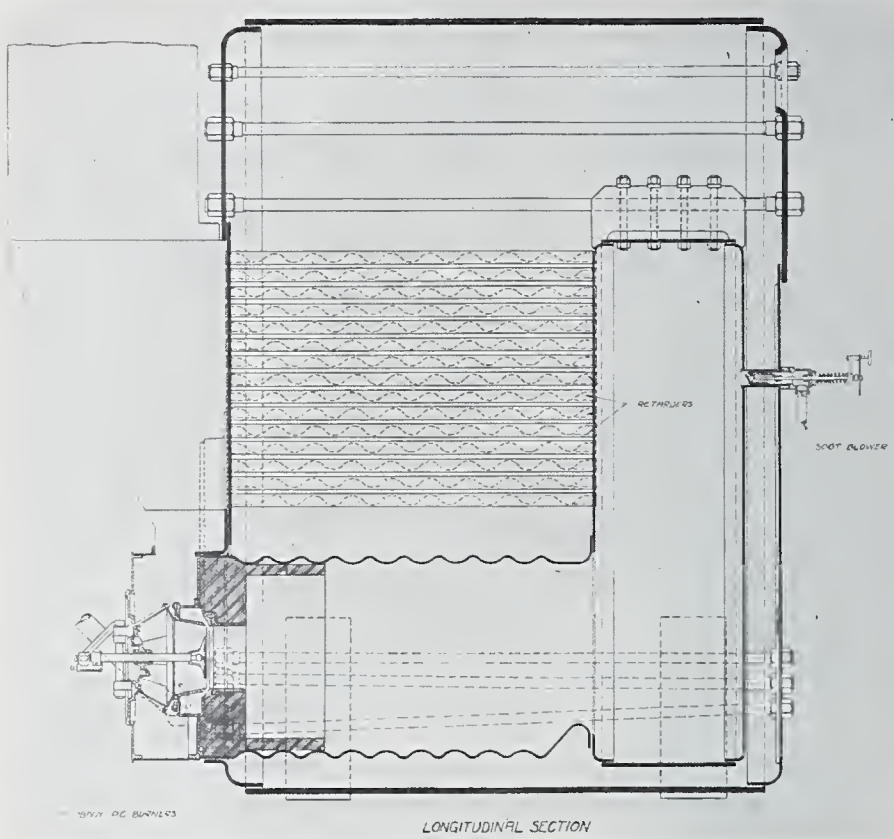

FIG. 2

stream and turn on the oil. This is clearly indicated in the illustration (Fig. 1) of the boiler front showing the combined burners in place. The oil burners also provide a ready and positive means for igniting the pulverized coal.

Although the various trans-Atlantic voyages of the *Mercer* have demonstrated the entire practicability of depending on powdered coal alone as a fuel, the fact that oil might be used as a substitute at any time, lent a feeling of security that would have otherwise been absent and gave encouragement to

those responsible for an experiment unusual in novelty and extent and dramatic in character. In fact, oil has been used at odd times on the *Mercer* when certain parts of the auxiliary equipment needed overhauling. The burners themselves have required neither alteration nor repair.

The sectional view of the burners (Fig. 2) will in connection with the photograph of the boiler front, clearly show the relationship of the various parts. Air for combustion from the usual heater of the Howden forced draft type passes down inside suitable ducts to the double fronts on the furnaces. It will be noted that there are no extended chambers to provide additional furnace volume, but the standard flush front arrangement usual in burning oil and hand-fired coal is retained. While thus adding to the difficulties of the combustion problem this flush front manifestly offers a more practicable arrangement, and does not encroach upon the fireroom nor the space in front of the tube doors.

From the double fronts the air passes through the doors of the registers which may be adjusted to suit varying conditions and which give to the air a rapid rotary motion due to their peculiar shape so that this air enters the furnace through a circular opening (15 inches in diameter) in the form of a rapidly rotating column. As the fuel is injected into and mixed with the air and ignition occurs, the rotating air gives a whirling motion to the resulting flame. This not only provides time for the fuel to burn completely in the short furnace of the Scotch boiler, but promotes the rapidity of combustion by the intermixing and tossing effect which is described under the now commonly used term "turbulence."

When oil alone is used, all the air for combustion enters through the register and mixes with the fuel which is thrown out from the atomizer tip as a hollow spray of finely divided particles. When powdered coal is used, only a portion of the air enters at the register, as the carrier air which supports the powdered coal passes through a chamber which is interposed between the register and front wall of the furnace. The mixture of coal and carrier air enters this chamber tangentially through the pipes shown at the sides of the air registers and passes in a circular path around the wall of the furnace throat. The circular box or chamber is made with the outer wall in the shape of a scroll or involute so that the cross section of the hollow casting is gradually reduced from the full area of the incoming air pipe to almost a negligible amount the termination of the complete circle. The inner or circular wall of this box of decreasing section is provided with a circumferential opening or slot, through which the powdered coal and carrier air enters the furnace throat. The outlet is so formed as to throw the coal inwardly toward the furnace in a thin stream in the shape of a converging cone. This cone of coal dust, therefore, penetrates the incoming rotating column of secondary or combustion air and is picked up by it and carried on into the furnace. Ignition takes place within a few inches of the furnace wall and the resulting flame takes on the same turbulent and rotating aspect of the previously described oil fire.

The effect of the involute chamber in combination with the circular outlet for the coal and air mixture results in a substantially uniform velocity throughout the chamber and prevents any settling or dropping out of the fuel.

It was not found necessary to use any great amount of refractory lining in the furnace, this being limited to a circle of brick extending only 18 inches from the inside of the front wall.

It will be noted that the front of the air register is hinged, and may be swung outward, thus giving a clear unobstructed passage into the furnace.

The engineers who developed this burner attach great importance to the fact that the powdered fuel is thrown inward into the secondary air stream and then outward by centrifugal force due to the rotary motion of the moving column. Thus one effect counteracts the other and results in thorough mixing and a short but not too widely extended flame. This construction also leaves the oil atomizer undisturbed in its regular position for burning oil, and greatly facilitates accessibility to the furnace and means for overhauling the equipment.

MR. JEFFERSON: I desire to elaborate somewhat upon what Mr. Vroom has just said, touching upon the other phases of the problem in connection with the use of pulverized fuel in marine boilers. The burner which has been described by Mr. Vroom in some detail we have found to be a very good burner and one which permits ready access to the interior of the furnace and does produce high flame turbulence, which is required in the small furnace of a marine boiler.

We who have been working on this problem of adapting pulverized fuel to marine boilers, however, believe that the burner alone cannot effect a complete solution and that of equal importance is the necessity of having very fine coal, much finer than is required in stationary plants fitted with large size refractory lined furnaces.

At the Philadelphia Navy Yard, in working out this problem, we made a study of the combustion from the products of combustion as well as from the furnace itself. Soot samples have been collected from the smoke box and sievings have been made of the same, making up a series of samples sized from 40 mesh or particles that pass through 420 microns down to the small sizes which pass through 46 microns, and then a B.t.u. determination has been made on each of the sized samples. The results of these analyses are shown on the attached curve.

It will be noted that up to the point of 149 micron sized sample, soot shows 9400 B.t.u. content but from that point on it drops down rapidly, the heat content drop from 149 microns down to 46 microns samples being about 2000 B.t.u.

It will be noted that this curve has a slight hump. This we have found characteristic of a number of samples taken and may be due to the possibility that the larger particles are not the results of pulverized particles, so that the original larger pieces, before going into the furnace itself, have a lower heat value than the smaller sizes.

CHAIRMAN GANDY: Is there any other discussion?

COMMANDER BROSHEK: There is just one word I want to say, and that is in connection with the part played by the various people in connection with

the development of powdered coal for marine use. The government is the agency which really started this development for marine purposes but a great deal of work had been done on shore. We all know that the government has very little money to spend for development work. The Shipping Board and the Navy do some experimental work at the Philadelphia Navy Yard. Nearly all the equipment that we have there is supplied by manufacturers. The manufacturers who place their equipment there, in nearly all cases, are required to pay for the cost of the installation and also for the cost of the test work; however, the manufacturers are benefited by that.

Another point I wanted to mention was in connection wirh future development work. We, the Shipping Board and the Navy, cannot go to work and develop additional equipment. We have material that produces results, but in asking you people to help us we want you to produce equipment that is better than the stuff we have. In other words, say it costs us 15 kilowatts to grind a ton of coal at the present time. What we want to do is to have equipment that will require, we will say, less than 10 kilowatts to grind a ton of coal. That is our idea in asking the producers and manufacturers to assist in carrying on this development work.

A great many people have contributed to this work and most of you people here are probably coal men—I assume you are, this being a coal conference—and I want to say right here that the coal men have helped a great deal. They have furnished us the coal we used at Philadelphia free of charge, they have all shown a great deal of interest in the tests that have been carried on, and it is appreciated. We have had numerous offers from coal men to furnish coal for additional tests.

Tests at Philadelphia and on board the *Mercer* will not stop. We feel we have only made a start and we want to keep on going. However, we also want you people on shore who manufacture the equipment to do what you can to bring down power consumption and to lower costs. If we get lower costs for pulverized coal installations, lower costs for producing pulverized coal, it is going to help us and it is going to help you. That is what we want.

CHAIRMAN GANDY: In Commander Broshek we see that we have a very fine example of coöperation of the government with the manufacturer and the coal man to the end that we might go forward in powdered coal use in marine service.

Gentlemen, this meeting is yours now. The subject is open for discussion.

MR. J. C. HOBBS (Diamond Alkali Company, Painsville, Ohio): As a matter of general information, I think it will be of value to have the author of the paper give us a little more detail about this pneumatic type of distributor. I couldn't quite determine from the paper whether the pneumatic type of distributor was the Blo-Gun, or whether it was some other piece of equipment that was being tested later.

Another piece of information which would be of value to those of us who are using pulverized coal in small furnaces on shore, is the length of the flame that is actually obtained in this type of furnace. It was not on the picture of Mr. Vroom, who discussed the paper, that retarders were installed in the tubes.

I would like to know what general effect those retarders give. Are they not likely to cause deposits of ash and accumulations which prevent the flow of gases through there? Is there any flame entering these tubes? What is the completeness of combustion? Those are a few of the questions that occurred to me.

It also occurred to me that the small diameter of this furnace, aside from the turbulence, and that perhaps the handicap of having a small furnace was really somewhat of an asset, whether the corrugations on the sides of the furnace have any particular effect, is also a conjecture.

I was particularly interested in all of the papers presented, and I believe we have had presentations here which rank with the highest that have been presented on the subject of pulverized coal.

On this matter of transportation of coal, looking at the broad side, it occurs to me that the tank car system for our conditions in this country is not any more practical than was found by the author in Germany. Whether or not an air-transport system, using either the pressure or the pump method, is practical, will depend, I believe, very much on the local conditions as to the costs or the practicability of handling raw coal, and upon the sizes of the furnace. I happened to become very familiar with an installation in which there are about fifty industrial furnaces served from one central system. In that case there is no question but what the pneumatic method of transporting coal is a decided advantage over the original method of transporting the raw, or fresh coal to individual furnaces. But it is because of the relationship between the amount of coal burned and the cost of handling the fresh coal, that makes it more practicable to us than that system.

An analysis has indicated that wherever the amount of coal is an appreciable size, that the central pulverizing system is not as economical as a unit system, shall I call it, in which the pulverizing is done right at the furnace, because of the total cost of transporting.

There are other systems which must not be overlooked in connection with the transportation of coal, for instance, the explosion hazard and the dust nuisance. Conveyance must be provided from all of these vents which are sieved and cannot be clogged, and allow the air pressure to build up and cause the coal dust to be distributed, particularly in industrial operations where open fires are present. All of those things require attention. Some of these dust nuisances while they may appear at first sight to be very minor in connection with certain products, are almost controlling facts.

The cost of transportation by air appears, as was stated by the author, to consist of a more or less fixed charge, plus a unit additional charge per unit of length. I am familiar with one installation where coal is being transported about three-quarters of a mile. In that case if you are honest and put in all of the cost, the total cost approaches 25 cents per ton. If there are not very many tons that is a small item. If it is a large installation, then 25 cents per ton is an item which should be reduced. The cost for shorter distances is conservatively less and is much less than the cost of handling raw coal through individual furnaces.

A central system with air transportation does not permit the use of waste heat for drawing. The emphasis placed on the elimination of moisture in the

air for transportation is well placed. Coal may leave the dryers with a very small fraction of 1 per cent of moisture, but that coal is warm, and the air which is used to transmit that coal will become saturated at the temperature that the coal leaves the pulverizer. As soon as that air in coal comes in contact with cold storage tanks, a condensation occurs which will cause considerable trouble in feeders and in plugging up the bins. It appears strange that you can have water dripping out of coal bins which contain coal originally dried to a very small fraction of 1 per cent. If that is the case it means with this central system provision must be made to insulate the bins against the cool air from the outside.

MR. JEFFERSON: The first question asked is regarding pneumatic distributor. The pneumatic distributor is really nothing but a flange about 2½ inches thick, located directly above the three-way division head where the main coal stream is divided into the individual coal streams for the three furnaces. In this flange are located three nozzles that have an axis approximately 15° sharper than the tangent to the bolt circle. Each of these nozzles has an independent connection to a compressed air manifold so that independent regulation of the pressure at the nozzle can be obtained. The air discharge from these nozzles starts a swirl in the coal stream. By changing the ratio of the pressures in the a, b and c nozzles, the center of the vertex of this swirl can be varied and by changing the basic pressures of the a, b and c nozzles, the pitch of the swirl may be varied. Through this pneumatic type of distributor it is possible to obtain a practically homogeneous mixture in the division head so as to have uniform quantity and quality of coal go into each of the three furnaces.

The objection to this type of distributor is that it means the addition of an air compressor to vessel's equipment.

The mechanical distributor, as originally installed, is very similar to a bread mixer or ice cream freezer paddle. This rotating paddle stirs up the coal stream and gives a homogeneous mixture. The mechanical distributor gave very good distribution when it ran but we nicknamed it the "Coolidge" distributor because it "did not choose to run" a lot of the time. The coal would leak out down into the bearings and seize the shaft, making it necessary to dismantle the distributor, clean out the bearings, and put it on the line again. As a distributor, it was very satisfactory when it operated but was not reliable and that is the main reason that we have substituted the pneumatic distributor in lieu of the mechanical distributor.

In reference to the length of flame in the boiler, I would say that the total length of the boiler from head to head is 12 feet. The furnace proper is about 8 feet long, to which is connected directly the combustion chamber, about 3 feet deep, following which is about 1 foot thick water-back. The Scotch boiler of course has completely water-cooled furnaces and combustion chambers.

Through the water back into the combustion chamber have been installed stay tubes, which we use for observation of combustion conditions in the furnace and with rates of combustion as high as 700 pounds per furnace, the flame would not come through the stay tube.

It is impossible to say just where the flame did terminate. A number of thermocouples were located in the back sheet, which was a precautionary measure taken to make sure that the sheet would not be subjected to severe flame impingement that would probably have caused boiler failure. During our numerous test runs, these thermocouples have never shown a temperature in excess of 600°, which would indicate that the flame did not hit the back sheet. As stated before, it is very difficult to say just how long the flame is, but from such observations as could be made through the stay tubes, it would appear that the flame was between 7 and 11 feet long.

In reference to the tube retarders used, would say that they are 4½ feet long and make 2½ turns in their distances. At no time, either at the Test Plant or on the seven voyages made by the *Mercer*, has there been any plugging up of the tubes due to ashes. The boiler at the Test Plant as well as those of the *Mercer* are fitted with rear end soot blowers made by the Power Specialty Company, and when operating at rates in excess of 500 pounds per hour to a furnace, tubes are blown every four hours. At lower rates they are blown every eight hours.

In reference to the diameter of flame, we feel that judging from the lack of carbon deposited in the furnaces, the flame does not hit the walls of the 42-inch diameter furnace. If it was hitting the walls of the furnace, it is believed that some of the larger particles that have not completed combustion would chill and catch on the walls of the furnace, giving a clinker all the way around the furnace. This has happened on one or two occasions but is the exception rather than the rule.

Velocity through the furnace is considered to be one of the most important factors in connection with the use of pulverized fuel in the small size furnace. During the 240-hour test, after operating the first 12 hours, we were in doubt whether we would be able to continue to 240 hours as the ash deposit had built up in the combustion chamber almost to the stay tube sight hole which I have mentioned before. However, after 12 hours the deposit did not appear to grow. At the end of 48 hours we changed the rate from 1,200 up to 1,400 pounds, and the ash deposit remained about the same. In the next 48 hours, we changed to a 1,600 rate and we noticed that the ash deposit began to diminish, and at the next change of rate, 48 hours later, when we operated at 1,800 pounds, there was an appreciable reduction in the ash content of the combustion chamber, and on the last 48 hours when we operated at 2,000 pounds, the ash deposit was practically eliminated. At the end of the test there was no ash in the combustion chamber. There was approximately a 3-inch depth of very hard slag in the furnace proper.

An explanation of the foregoing is that at the low rate we did not have great enough velocity to carry the ash through the boiler, with the result that there was a heavy precipitation until the cross section of the gas passage had been reduced so as to build up a velocity sufficient to carry the ash out and as the velocity of the gases was increased at the higher rates it was necessary for them to scour out some of this deposit. All of this was not scoured out, however, and as we went to the higher rates with increased temperature, some of it became slag. We found on the *Mercer* that the best method of operation is not to remove the ash during the voyage. At the end of fourteen days' steam-

ing you will have about 3-inch deposit in the bottom of your furnace, running in alternate layers of about 1-inch coke and 1-inch very hard slag. Therefore, our usual method of procedure is to remove ashes only at the termination of each trans-Atlantic passage.

On the first voyage of the *Mercer*, on her arrival at Rotterdam, we cleaned out four furnaces and left the ash deposit in the other two, and on the vessel's return to the United States we found 3-inch deposits in the four furnaces that had been cleaned out but in the two where the ash deposits had been permitted to remain, we found about an 8-inch deposit.

MR. HOBBS: What is the construction of the horse collar?

MR. JEFFERSON: The horse collar is that part of the furnace where the cylindrical furnace joins the combustion chamber proper. It takes its name from the fact that it is shaped like the horse collar characteristic of trucking horse harness. The area through the horse collar is approximately 40 per cent less than the area through the furnace proper. This acts very similar to the bridge wall of the return tubular boiler and the water tube boiler found in stationary plants. The main purpose, however, of the horse collar was from a construction point, which would permit renewal of furnaces and at the same time retain the flange type of construction. In a number of the older boilers, built with straight furnaces and where the lapped type of joint is used, an artificial horse collar, built up of refractory material, has been found desirable.

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